Summary of

Massachusetts Water Resources Authority
Benthic Workshop

held

May 24, 1996

hosted by

MIT Sea Grant

prepared by
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and

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ms-42

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OVERVIEW

The Massachusetts Water Resources Authority (MWRA) Benthic Workshop summarized in this document was held on May 24, 1996. The purpose of the workshop was to present the 1995 data from the benthic monitoring tasks as well as provide an initial forum to integrate results across the various disciplines. In addition, Workshop presentations included a review of monitoring questions and hypotheses posed in the Phase II Post Discharge Monitoring Plan (November 30, 1995). To stimulate discussion, meeting participants were provided with "score cards" containing relevant hypotheses, warning levels and action levels used in the MWRA monitoring program. Each participant was asked to evaluate these hypotheses, comment on their validity, and offer suggestions.

During the discussion session which followed the scientific presentations, relevant issues, questions, and suggestions raised by participants were considered. These comments were incorporated into a set of issues and recommendations which were discussed at the Outfall Monitoring Task Force meeting held on May 31, 1996.

INTRODUCTION

The 1996 Benthic Workshop was held at the Massachusetts Institute of Technology on May 24, 1996. This workshop presented 1995 monitoring data and compared these results to data collected in previous years. There were approximately 51 attendees, including MWRA personnel, regulators, academics, nonprofit environmental groups, and project scientists. A list of attendees is included in Appendix A.

Jerry Schubel (New England Aquarium) moderated the workshop and presented the overall goals and objectives of the workshop. Ken Keay (MWRA) provided an overview and discussed the goals of the MWRA monitoring program. Summaries of 1995 benthic data and comparisons to previous years were presented by project scientists. A final discussion session led by Jerry Schubel helped to streamline issues and comments from the workshop participants.

The goals of the workshop were to:

- present and discuss 1995 monitoring data, and provide an initial forum for integration of results by project scientists prior to drafting the annual report;

- evaluate the adequacy of the current monitoring plan for benthic resources in meeting the overall goals of the monitoring program;

- determine the adequacy of baseline data in understanding the benthic conditions in the Boston Harbor, Massachusetts and Cape Cod Bay ecosystems in order to evaluate the effects of the relocated outfall;

- evaluate existing monitoring parameters and determine if additional (or reduced) set of parameters should be measured;

- assess the adequacy of spatial and temporal coverage in meeting the goals of the Harbor and Outfall Monitoring (HOM) plan;

- discuss appropriate indicators of change, acceptable levels of meaningful change, and assessment endpoints for benthic resources in the Boston Harbor, Massachusetts, and Cape Cod Bay ecosystems;

- review current methodology and identify any issues regarding monitoring, data analysis or data interpretation; and

- review the overall goals of the monitoring program and determine whether they are being attained.

One critical component of this workshop was to reevaluate the hypotheses used in the monitoring program. Project scientists were tasked with discussing relevant hypotheses, whether these hypotheses are appropriate questions for evaluating the effects of the relocated discharge, and whether the draft MWRA post-discharge monitoring design will be able to answer these questions.

The workshop agenda, abstracts from each scientific presentation, Phase II hypotheses, and a summary of key points and discussion items are provided after this section. The list of participants is provided in Appendix A, written correspondence pertaining to the workshop is provided in Appendix B, and copies of overheads and graphics from the presentations are provided in Appendix C.

WORKSHOP AGENDA AND ABSTRACTS

MWRA Harbor and Outfall Monitoring (HOM) Workshops, Friday May 24, 1996

Coordinated by ENSR, hosted by MIT Sea Grant Office

at MIT, Civil and Environmental Engineering Building (Parsons Lab, Bldg. 48, Room 316)

EFFLUENT, FISH AND SHELLFISH WORKSHOP AGENDA

WELCOME AND INTRODUCTION 08:30 AM - 08:55 AM

08:30 AM Jerry Schubel, New England Aquarium (10 min)

08:40 AM Ken Keay, MWRA: Overview & goals of monitoring program (15 min)

PRESENTATIONS 08:55 AM - 10:30 AM

08:55 AM Effluent Characterization Studies in Massachusetts Bay- Eric Butler, ENSR (20 min)

09:15 AM Stable isotope measurements in Boston Harbor and Massachusetts Bay - Anne Giblin, MBL (15 min)

09:30 AM Histopathology and Chemistry of Flounder - Michael Moore, WHOI (20 min)

09:50 AM Lobster tissue burdens: current status and trends - David Mitchell, ENSR (20 min)

10:10 AM Caged mussel studies - Phil Downey, Aquatec (20 min)

DISCUSSION 10:30 AM - 11:30 AM

LUNCH (provided) 11:30 AM - 12:00PM

BENTHIC WORKSHOP AGENDA

WELCOME AND INTRODUCTION 12:00 PM - 12:40 PM

12:00 PM Jerry Schubel, New England Aquarium (10 min)

12:10 PM Overview and goals of monitoring program - Ken Keay, MWRA (30 min)

PRESENTATIONS 12:40 PM - 03:55 PM

12:40 PM Physical and biological processes in the nearfield area as revealed by sediment profile imaging - Donald Rhoads (20 min)

01:00 PM U.S. Geological Survey Sediment Studies, Mike Bothner, USGS (15 min)

01:15 PM Metals Chemistry - Gordon Wallace, UMB (20 min)

01:35 PM Sediment Organics - Eric Butler, ENSR (20 min)

01:55 PM Break (30 min)

02:25 PM Softbottom benthic infauna in Massachusetts Bay - Jim Blake and Brigitte Hilbig, ENSR (40 min)

03:05 PM Benthic nutrient flux - Brian Howes, WHOI (30 min)

03:35 PM Results of video surveys in the vicinity of the Massachusetts Bay outfall site - Barbara Hecker (20 min)

DISCUSSION 03:55 PM - 05:00 PM
ADJOURN 05:00 PM

Physical and Biological Processes in the Nearfield Area as Revealed by Sediment Profile Imaging

Donald C. Rhoads

ABSTRACT- Sedimentary and benthic biological facies in the Nearfield area are strongly influenced by a West to East gradient in kinetic energy. Five stations on the western side of the surveyed area represent a relatively low kinetic energy regime (NF-8, NF-9, NF-10, NF-12, and NF-21) and are dominated by silt-clay muds. Some of these stations show intercalations of sand at depth in profile images. This fine-scaled stratigraphy suggests that spatial-temporal shifts in sediment type (silt-clay (>4 phi) alternating with very-fine sand (4-3 phi) takes place within the western edge of the area related to fluctuating levels of fine-grained sediment transport and bedload transport.

In the baseline survey of 1992, all stations consisted of sand. No surface muds were observed. The change from very fine sand (3-4 phi) in 1992 to silt-clay muds (>4 phi) in 1995 at the above stations marks a significant change in bottom facies at the Nearfield monitoring area.

In 1995, a narrow band of current-scoured very fine sand (4-3 phi) and fine sand (3-2 phi) exists immediately East of the western mud patch (Stas. NF-5, NF-7, NF-18, NF-13, NF-14, NF-15, NF-16, and NF-20). The highest average kinetic energy is inferred to exist on the eastern-most side of the area near the location of the diffuser. The bottom is dominated by fine sand (2-3 phi) and coarser material (Stas. NF-4, NF-23, Nf-17, NF-19 an NF-2). Noted exceptions are Stations NF-22 and NF-24 where local pockets of silt-clay exist in an otherwise clean sand facies. The highest concentrations of total organic carbon (TOC) are found at Stas. NF-8 (2.0%), NF-21 (1.4%), NF-22 (1.3%), and NF-24 (2.8%). Stations NF-21, NF-22, and NF-24 are also inferred to represent high sedimentation rate stations based on deep penetration of the sediment profile camera into homogeneous sulfidic (i.e. low reflectance) muds.

The depth of the apparent redox potential discontinuity (RPD) is shallowest in the western muddy stations and deepest in the sand facies to the east. The depth of the apparent RPD reflects the reducing capacity of the sediments (muds > clean sands) and the rate of turnover of the sediment by infaunal organisms and wave and current reworking. The RPD depth-frequency distribution is unimodal with most values falling within the 2.16 to 3.24 cm depth class (mean= 2.98 cm, N=20 stations). In the 1992 baseline survey, the distribution was also unimodal with the same major modal depth class but the mean value was slightly lower (2.64 cm; N=16). (See also Hypothesis Testing).

The sedimentary facies pattern described above is associated with different benthic assemblages. The western muds consist of mixtures of Stage I and III seres while the eastern sands are dominated by Stage I polychaetes. Stations located at, or near, the edge of the sand-mud boundary are ecotonal mixtures of Stage I, II, and III seres. Amphipod tube mats (Stage II) were imaged for the first time at Stas. NF-5, NF-4, NF-21, and NF-16.

Organism-sediment indices (OSI's) range from a low of +3 (Sta. NF-7) to +9 (NF-9 and F-16). Prior experience with mapping the OSI parameter in Boston Harbor and Mass. Bay indicates that physically or chemically disturbed benthic habitats tend to have OSI values < +6. The overall frequency distribution of OSI values in 1995 is bimodal with a major mode falling within the 6.5 to 7.5 OSI class

and a subordinate mode falling within the 4.5 to 5.5 OSI class. In the 1992 baseline survey, the distribution was markedly polymodal with the lowest values (OSI= 3.5 to 4.5) at Stations NF-2 and NF-13. Three other peaks in the OSI class distributions are co-equal (5.5-6.5, 7.5-8.5, and 8.5-9.5). The OSI frequency distribution in 1992 was interpreted as reflecting organism-sediment responses to markedly different disturbance patches. The 1995 OSI distribution also reflects a mosaic of disturbance patches but most OSI values fall within intermediate levels of benthic disturbance. This inference is supported by the presence of *Ampelisca* at ecotonal stations and by the presence of silt-clay muds in the western part of the area mapped in 1995 suggesting lower levels of kinetic energy relative to 1992 where surface sands dominated all stations.

Hypothesis Testing

Sediment RPD (Hypothesis B5)

The sediment (apparent) RPD will not decrease to 50% of the average baseline depth at the nearfield muddy (>70% fines) stations.

Five stations in the 1992 baseline study qualify as having >70% fines (NF-8, NF-20, NF-16, NF-12, and NF-2). The mean apparent RPD depth at these stations ranged from 0.9 to 4.8 cm with a mean of 2.7 cm. The **Action Level** is therefore 1.3 cm (50% decrease in the population mean).

In 1995, three baseline stations visited in 1992 were fine grained (>70% fines): NF-8, NF-16, NF-12. The mean apparent RPD depth at these stations ranged from 2.3 to 3.7 cm with a mean of 2.9 cm. The **Action Level** has not been reached, therefore the null hypothesis is accepted.

Sediment RPD (Hypothesis B6)

The depth of the sediment RPD will not decrease by more than 20% per year (relative to the average baseline depth) in the muddy areas of the nearfield for any three consecutive year period.

The **Action Level** of 20% (0.54 cm/yr), resulting in a decrease to 2.2 cm between 1994 and 1995, could not be tested. Data for 1994 as shown in Fig. 2-15, pg 2-37 of the MWRA Phase II Post Discharge Monitoring Report (Nov. 1995) could not be used to test this hypothesis because of different observation methods used between the two years (coring in 1994 and SPC *in-situ* imaging in 1995).

Contaminants in sediments of Massachusetts coastal areas: present assessments and considerations for monitoring change over time

Michael H. Bothner, Peter W. Gill, and Richard P. Signell U.S. Geological Survey, Woods Hole, Mass.

One objective of this workshop is to review the techniques that will be used to quantify any changes in contaminant levels in sediments caused by the new sewage outfall. Establishing the cause of any future change in sediment contaminant loadings requires basic knowledge about the spatial/temporal variability of sediment characteristics and processes that influence sediment transport and deposition. These issues are addressed in part by each of the components of the ongoing USGS program in Massachusetts Bay. The program includes: 1. long term current and sediment transport observations; 2. sediment geochemistry and assessment of contaminant inventories; 3. circulation and sediment transport modeling; 4. sediment texture and geochemical data base development; and 5. geologic mapping. A number of recent results from this program define the natural variability in sediment contaminant levels, identify the seasonal cycles of sediment resuspension, and estimate the total inventory of silver in depositional areas of Massachusetts and Cape Cod Bays.

Analyses of silver and Clostridium perfringens spores in surface sediment (0-0.5 cm) collected at 4 month intervals for 6 years at the same location in western Massachusetts Bay revealed nearly constant values for 3 years followed by a 2 fold increase in their concentrations that persisted for approximately 1 year. This increase occurred immediately after an unusually large storm which is assumed to be responsible for the change.

Results from a time series sediment trap, with 9 day sampling intervals, indicated that the rate of sediment collection was closely correlated with the intensity of bottom stress generated by surface waves. However, in late summer, the measured sediment collection rates were higher than expected given the low calculated bottom stress, and in late winter the trapping rate was lower than expected from the high bottom stress. One hypothesis is that sediments accumulating during quiet periods of July and August are more easily resuspended in late summer and fall than the residual sediments that are present in late winter. These general trends are observed during each of the 6 years of measurements. The observation of seasonal resuspension response to bottom stress, although not fully explained, will be an important consideration for sediment transport modeling.

The components of the USGS program have contributed to the discovery and explanation of the anomalously high accumulation of silver in the sediments of Cape Cod Bay which appears to have been derived from sewage and other discharge to Boston Harbor. Processes identified as possible contributors to the observed silver distribution include: resuspension and offshore transport from the future outfall area during storms, southerly mean currents parallel to depth contours in western Massachusetts Bay, slower recirculating currents in Cape Cod Bay, and the existence of a depositional environment for fine grained sediments in Cape Cod Bay. We made a crude estimate of the total inventory of anthropogenic silver in fine-grained sediments of Stellwagen Basin and Cape Cod Bay based on analysis of 6 cores. The estimate suggests that there is about 4 times more silver in Cape Cod Bay than in Stellwagen Basin. The annual discharge of silver in 1994 by MWRA represents about 2% of the total inventory of silver in these offshore depositional areas.

Metal Distributions in Surface Sediments in Massachusetts Bay - Control by Ambient Dissolved Metal Concentrations and Sediment Organic Carbon

Gordon T. Wallace

Metal concentrations in surface sediments taken between 1992 and 1995 from both nearfield and farfield stations fall into distinct patterns when regressed against organic carbon content. Although there is considerable year to year and within site variability, the sediment data appear to be consistent (with the exception of the 1992 data) when normalized to reported organic carbon concentrations. Regression of data from the northwest region of Massachusetts Bay, including most of the stations designated as nearfield stations, as well as inshore farfield stations near the Boston Harbor entrance, fall along a regression slope that is relatively constant from year to year. This slope is distinctly greater than that derived using data from farfield and one nearfield stations which also show consistency from year to year. The data are consistent with known circulation, source, transport and distribution patterns of metals in the Bay. Surface sediment concentrations in the two sets of samples appear to be largely controlled by equilibration between dissolved metal concentrations in the overlying water column and the organic matter of the surficial sediments. These observations suggest that sediment concentrations of selected metals may be reasonably predicted based on estimates of future organic matter accumulation in the sediments and changes in mean water column concentrations.

Recommendations for changes to improve sample collection and processing will be made as well as recommendations for further work to improve the ability to accurately predict changes in sediment quality under different contaminant loading scenarios and sediment composition. The proposed changes may further improve the ability to use surface sediment composition as a sensitive tool for detecting changes in water as well as sediment concentrations of metals in Massachusetts Bay.

Organic Constituents in Massachusetts Bay Sediments, MWRA Harbor and Outfall Monitoring Program, 1995.

Harbor and Outfall Montitoring Task Force, Workshop, MIT, May 24, 1996

In 1995, 22 sediment samples were collected from 11 Farfield stations (including 11 replicate samples) and 23 samples were collected from 20 Nearfield stations (including 3 replicate samples) and analyzed for polycyclicaromatic hydrocarbons (PAH), linear alkylbenzenes (LAB), pesticides, and polychlorinated biphenyls (PCB).

The laboratory that analyzed the 1995 samples was not the same laboratory that analyzed the sediment samples from 1992-1994 for the MWRA and despite the fact that the two laboratories applied the same analytical methods the comparability of the data was a concern. Evidence that the laboratories produced comparable data include: the ranges of constituent concentrations across stations was similar in 1995 to that of prior years; in general, stations that had historically exhibited relatively higher concentrations and stations that had exhibited relatively lower concentrations did so again in 1995; the geometric mean concentrations for all organic parameters in the 8-station region within 2 km of the proposed 2km long discharge pipe (Coats, 1995) with which comparisons could be made did not show any significant differences between the 1995 mean and the baseline mean (established with 1992-1994 data); and plots of concentration (normalized to total organic carbon [TOC]) versus time for numerous selected stations did not reveal any systemic differences between the results of the 2 laboratories.

The absolute concentrations of certain groups of constituents relative to ecologically relevant concentrations is also a concern. No analyte or groups of analytes for which NOAA ERMs (environmental effects median range) or EPA sediment criteria exist exceeded 90% of those values. The parameters for which these assessments could be made include: total PAH; total PCBs; total DDT; 4,4'DDE; acenaphthene; phenanthrene; and fluoranthene.

In summary, the organic chemistry results for the 1995 were consistent with data from prior years, show generally low concentrations for the parameters measured, and in no instance exceed either 90% of NOAA ERMs or 90% of EPA sediment criteria.

Abstract - Brigitte Hilbig

The softbottom benthic communities in the near-, mid-, and farfield were characterized based on the August 1995 sampling effort. The most common dominant species throughout the study area were *Prionospio steenstrupi*, *Spio limicola*, and *Mediomastus californiensis*; in the mid- and nearfield, peak spionid densities were about 20,000 individuals m^{-2} (several stations around midfield/nearfield boundary), and in the farfield about 50,000 individuals m^{-2} (station FF1A off Gloucester and FF9 in central Massachusetts Bay). *Mediomastus* reached peak densities of about 12,000 to 16,000 individuals m^{-2} in finer grained sediments at midfield stations NF8, 10, and 12 and FF10, 12, and 13. Cirratulid polychaetes were among the dominant species of several mid- and nearfield stations, but less abundant in the farfield. Syllidae were abundant at some of the sandier stations in the nearfield, where two species of *Exogone* reached peak densities of 7000 to 14,000 individuals m^{-2} (stations NF13, 14, and 23). Paraonids were most abundant at midfield stations close to the Harbor, with *Aricidea catherinae* occurring at densities of 14,000 to 27,000 individuals m^{-2}. In the farfield, this species was replaced by its congener *A. quadrilobata*, with densities being much lower than in the midfield.

Total infaunal density varied between 700 and 3500 individuals per grab (0.04 m^2) in the near- and midfield and between 1100 and 8000 individuals per 3 grabs (0.12 m^2) in the farfield (about 360 to 2700 individuals per grab). The highest infaunal densities were supported by muddy sediments in the midfield, the lowest by sandy substrata in the mid- and nearfield but also at station FF4 in Stellwagen Basin where sediments were very fine. Species richness ranged from 45 to 85 in the near- and midfield and from 56 to 108 in the farfield; the higher species richness in the farfield may be an artifact of the sampling design (mostly single versus replicated samples). The highest number of species was generally found in mixed sands and silts in the mid/nearfield and farfield station FF9, while very fine-grained and very sandy sediments supported fewer species.

Diversity (expressed as rarefaction) ranged from about 16 to 30 expected species per 100 individuals in the mid- and nearfield and 19 to 26 expected species per 100 individuals in the farfield; diversity was generally lowest at sandy stations, but sediment grain size was not the only factor influencing this parameter; some of the highest diversities were observed at sandy midfield stations as well.

Several clustering and ordination techniques were used to explore similarities among stations and the infaunal assemblages causing these similarities. In the near/midfield, one or two benthic infaunal assemblages inhabiting muddy sediments could be defined, and two or three sand-dwelling assemblages. The mud assemblages were dominated by spionids and/or capitellids, and the sand assemblages were defined by *Exogone* spp., *Corophium crassicorne*, *Polygordius* sp., and *Cerastoderma pinnulatum*.

In the farfield, three different assemblages were present, with the species composition influenced mostly by distance from shore and geography, rather than sediment grain size. The two assemblages in Massachusetts Bay were both dominated by *Prionospio steenstrupi*, but differed in the less abundant species that had different depth preferences. The two Cape Cod Bay stations had an infaunal assemblage characterized by *Cossura longocirrata*, Tubificidae sp. 2, and other polychaetes such as *Apistobranchus typicus*.

Rates of Sediment and Watercolumn Respiration within Massachusetts Bay and Boston Harbor: Relating to Oxygen Dynamics and Infaunal Assemblages

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Rates of oxygen uptake were measured throughout 1995 along the organic matter gradient from Boston Inner Harbor to the outer edge of the nearfield grid (Sta NO4). These data were coupled with season measurements of oxygen uptake, nitrogen regeneration and denitrification within Harbor and Bay sediments. Some of the major results are detailed below.

Massachusetts Bay: Rates of respiration in bottom waters varied over 5 fold throughout the year. Rates were directly related to organic matter availability and temperature. Oxygen uptake was highest when the watercolumn was unstratified with respiration decreasing to a low relatively constant rate throughout the period of stratification. The decline in bottom water respiration during stratification appears to be associated with reduction in the transfer of labile organic matter to the hypolimnion. Estimates of total oxygen uptake in bottom waters during stratification were comparable to the measured total oxygen uptake by sediments and watercolumn, each contributing about equally to system respiration. These data suggest that ventilation of bottom waters during stratification is likely small.

Rates of sediment oxygen uptake and nutrient regeneration were comparable to previous studies (within 15%). The inter-annual stability of these integrative process level measures strongly indicates that they will be a sensitive tool for detecting relatively small changes in carbon enrichment resulting from nutrient enrichment. In addition, since benthic respiration appears to play a major role in bottom water oxygen depletion, changes in uptake rates may allow prediction of changes in the extent of annual oxygen depletion. Our preliminary carbon budget based upon measures of carbon production and decomposition within Bay waters and sediments suggests that organic matter cycling within the nearfield is relatively tightly coupled. Initial analysis suggests that comparable masses of organic matter are produced and respired within the nearfield region and that respiration does not require large imports of organic matter from inshore sources.

Boston Harbor: Rates of total sediment community respiration, while showing significant inter-annual variability, appear to be increasing in portions of Boston Harbor. Seasonal measurements of carbon and nitrogen cycling in surficial sediments, part of the MWRA monitoring program, indicate that rates of organic carbon and nitrogen remineralization and denitrification were higher in 1995 than reported in each of the previous years of monitoring. Concurrent with the measured increases in rates of diagenesis has been rapid colonization of Harbor sediments by infauna, particularly the development of dense amphipod mats (Ampelisca and Leptocheirus).

Remineralization rates and denitrification were significantly enhanced in areas densely colonized by amphipods compared to areas with lower total infaunal densities. Infauna affected carbon mineralization directly through their metabolism and indirectly through their irrigation of the surficial sediments. The result was increasing oxidation of surficial sediments and higher rates of nitrification/denitrification. These results suggest that the nitrogen and carbon transformations within the Harbor and transport to Massachusetts Bay may be very dynamic under changing environmental quality. The temporal nature of these biologically mediating effects and their potential role in accelerating nutrient removal from the Harbor will be elucidated by the continued monitoring of this system.

Nearfield Hardbottom Video Survey

by

Barbara Hecker

Hecker Environmental Consulting

A video survey of hardbottom habitats was conducted with a remotely operated vehicle (ROV) in the vicinity of the new sewage outfall in Massachusetts Bay between June 14-16, 1995. Video footage and still photographs were collected at six transects on drumlins both near and further away from the outfall. The video tapes and stills were semiquantitatively analyzed for recognizable taxa and sea floor characteristics. More than 11,300 individuals in 78 taxa, and 4318 individuals in 74 taxa, were counted on the video and stills, respectively. Drumlin topography appeared to be a major factor in determining the composition of benthic communities. Communities on the top of drumlins were dominated by algae, while communities on the flanks were dominated by invertebrates. Tops of drumlins also supported moderate to high abundances of green sea urchins, horse mussels, juvenile star fish, and cunner. Flanks of drumlins supported moderate to high abundances of encrusting and attached organisms. A sediment covered topographic low at the eastern end of the outfall was inhabited by a sparse mix of attached and mobile invertebrates. Some taxa, such as algae, the green sea urchin, and the horse mussel exhibited strong habitat preferences, while other taxa such as some of the encrusting organisms, the cunner and juvenile Asterias were seen in many of the areas surveyed. Some areas were very homogeneous in terms of substratum type and benthic community composition, while other areas exhibited a variety of patchily distributed habitats and taxa. Some of the variability observed in the data could be related to difficulties in resolving taxonomic designations of some of the encrusting taxa. This was particularly relevant to data obtain from video tapes. However, a fair amount of variability in the data appears to reflect the inherently patchy nature of hardbottom habitats.

Still photographs provided finer details of the structure of the hardbottom communities than could be discerned from video tapes. This is based on the higher resolution afforded by stills. The two techniques are complimentary in that the video footage provides greater areal coverage of the habitats, while the still photographs provide more accurate assessments of the taxonomic composition of the communities inhabiting them. This survey has addressed spatial variability in the nearfield hardbottom benthic communities at one point in time. Future surveys will be aimed at addressing the temporal stability of these communities. We recommend that future surveys shift more emphasis to still photography to provide more accurate assessments of the taxonomic composition of the benthic communities, since this data would facilitate detection of possible future impacts related to the outfall.

PHASE II BENTHIC HYPOTHESES

Hypotheses to be tested during Phase II of the MWRA Outfall Monitoring Program *(continued).*

BENTHIC

Community structure

B1: The diversity of the nearfield benthic community at muddy stations (>70% fine grained sediments) within the nearfield area will not decrease to one-half the baseline diversity.

B2: The diversity of the nearfield benthic community at stations with primarily coarse grained sediments will not decrease to one-half the baseline diversity.

B3: The diversity of the benthic community outside of the area of predicted impact will not show a statistically significantly downward trend relative to the baseline for any three consecutive year period.

B4: The composition of the soft-bottom benthic community outside of the SEIS predicted area of impact will not change to one typical of a degraded benthic community.

Sediment RPD

B5: The sediment RPD will not decrease to 50% of the average baseline depth at the nearfield muddy (greater than 70 percent fine grained sediments) stations.

B6: The depth of the sediment RPD will not decrease by more than 20% per year (relative to the average baseline depth) in the muddy areas of the nearfield for any three consecutive year period.

Contaminants

B7: The sediment concentrations of metals or organic contaminants at the granularly-stable midfield (2-7 km) stations will not exceed 90% of the NOAA ER-M values.

B8: The concentrations of contaminants (metals or organic compounds) at the granularly-stable midfield stations will not exceed 90% of available EPA sediment criteria.

ALTERNATE BENTHIC COMMUNITY HYPOTHESES

Community structure

B1: The mean infaunal community at granularly-stable midfield (2-7 km) stations shall not change by more than three standard deviations from baseline conditions after allowing for a 20% risk of falsely observing changes of this magnitude (type I error = $\alpha = 0.20$) and a 20% risk of not observing change of this magnitude when they in fact exist (type II error = $\beta = 0.20$). The infaunal community structure shall be specified with a robust infaunal parameter that accounts for gross differences in granularity among midfield stations and that is sensitive to changes in both rare and abundant taxa.

COMMENTS FROM WORKSHOP DISCUSSION SESSION

After each scientific presentation and in the general discussion session, workshop participants discussed issues, questions, and comments relevant to the benthic monitoring program. The main themes from these discussion sessions are highlighted below.

MAJOR TOPICS FROM DISCUSSION SESSIONS:

Physical and biological processes in the nearfield area

- Two participants suggested that sediment profile imaging may not return good estimates of Redox Potential Discontinuity (RPD) depth. One participant recommended the use of actual measurements of redox profiles in sediment cores if RPD depth remains a "trigger" parameter.

- The speaker suggested focusing on local depositional areas and recommended considering station NF-24 as a long-term sediment chemistry station because it is a strong depositional area.

U.S. Geological Survey Sediment Studies

- Some participants agreed with a suggestion to measure contaminants only in the silt-clay fraction of bulk sediment samples.

- The speaker, along with several participants, expressed an interest in using sediment traps as an analysis tool. Sediment traps provide early detection information, have good sensitivity, and serve as an index of sediment toxicity.

Metals Chemistry and Sediment Organics

- Several participants questioned the utility of the modeling approach presented for metals data. Other participants, however thought that the modeling approach is a potentially useful predictor of outfall effects.

- Some participants suggested that sediment contaminant chemistry analyses may not need to be carried out in the remaining baseline years, and that post-discharge frequency could be conducted on a less than annual basis.

- Several participants noted that hypotheses and thresholds need to be reevaluated, and that the ER-M thresholds suggested in the Phase II monitoring draft may be inappropriate.

- One participant suggested analyzing all sample variables from the same homogenized sample in order to improve resolution.

Softbottom benthic infauna in Massachusetts Bay

- There was some consensus that a synthesis of the natural history-based approach used in the analysis of the 1995 data and the multivariate approach carried out in 1994 shows most promise in developing hypotheses and triggers for tracking and explaining outfall effects on infauna.

- One participant questioned if additional baseline data are necessary at the deepwater and Cape Cod Bay stations.

- Several participants indicated that the term "degraded community" must be clearly defined.

Benthic nutrient flux

- One participant questioned whether additional baseline years are necessary to fully develop the model presented.

- Some participants suggested that the Massachusetts Bay stations may be adequately characterized, but added that continued monitoring for developing changes at the Harbor stations should be pursued.

GENERAL COMMENTS AND QUESTIONS:

- Several hypotheses need revision.

- It may be possible to cluster hypotheses which have an obvious overlap and create a "capstone" hypothesis for each cluster. Hypotheses should be created which cross programmatic lines.

- One reviewer reiterated that clear statements between biological sampling and goals of monitoring are needed. In addition, a consensus needs to be made on which parameters will be used to assess change. A specific theoretical model should be chosen to explain changes in the system.

- One participant pointed out that it is difficult to distinguish between what contaminants originate from the diffuser and what contaminants originate from the harbor.

- One reviewer suggested that diversity indices should not be used to determine infaunal changes due to the outfall. Multivariate analysis and community structure have great discriminatory power, but low explanatory power. Therefore, it is hard to tell if infaunal changes are due to the outfall or any other event. The final suggestion was to place more emphasis on natural history observations of benthic communities and less on computer analysis. In addition, clues from hardbottom studies may be able to provide clues to softbottom changes.

- Several participants suggested that it is necessary to synthesize all datasets collected over the last 4 years.

- One participant stated that chemists would like to know about the species-specific differences in bioturbation for benthic species. This statement led to a general comment that there is a need to improve communication across disciplines of the MWRA monitoring program.

- One participant suggested that the effects of bottom fishing on the benthic community should be investigated.

APPENDIX A

Workshop Attendance

APPENDIX A

Attendance at the MWRA workshops

5/23/96 all day Water Quality
5/24/96 A.M. Effluent; Fish
5/24/96 P.M. Benthos

x		x	Adams, Eric	MIT
x			Anderson, Don	WHOI
x			Anderson, Steve	Anderson & Kreiger
x	x	x	Benaway, Heather	UNH
x	x	x	Blake, Jim	ENSR
	x	x	Boehm, Paul	ADL
x			Bollens, Steve	WHOI
x			Borkman, Dave	URI
	x	x	Bothner, Mike	USGS
x	x	x	Boudrow, Rob	UNH
x			Bowen, Jim	UNC
x			Bridges, Leigh	MDMF
	x	x	Butler, Eric	ENSR
x	x	x	Butman, Brad	USGS
x			Cambareri, Tom	CCC
x	x		Carlisle, Bruce	MCZM
x	x	x	Chen, Bob	UMB
x			Cibik, Steve	ENSR
x			Coniaris, Cathy	UNH
x			Connelly, Brian	WHOI
x	x	x	Connor, Mike	MWRA
x			Daley, Patty	CCC
	x	x	Downey, Phil	Aquatec
	x	x	Estrella, Bruce	MDMF
	x	x	Fredette, Tom	COE
x	x	x	Gallagher, Gene	UMB
x		x	Galya, Don	ENSR
x			Geyer, Rocky	WHOI
	x	x	Giblin, Anne	MBL
x	x	x	Gould, Diane	MCZM
	x	x	Grob, Elizabeth	MCZM
x	x	x	Hall, Maury	MWRA
	x	x	Hecker, Barbara	Hecker Envir.
		x	Hilbig, Brigitte	ENSR
x	x	x	Ho, Nancy	APCC

x		x	Howes, Brian	WHOI
x	x	x	Hunt, Carlton	Battelle
	x	x	Ika, Ravi	Harvard
x			Isaac, Russell	MA DEP
x	x	x	Jaworski, Norbert	EPA
x	x	x	Keay, Ken	MWRA
x			Kelly, Jack	Battelle
		x	Kropp, Roy	Battelle
		x	Krueger, Elaine	MA DPH
x			Lacouture, Richard	ANS
x	x	x	Liebman, Matt	EPA
x	x	x	Loder, Ted	UNH
	x	x	MacLean, Sharon	NMFS
x	x		Malone, Tom	U MD
x			Mayo, Stormy	CCS
x	x	x	McCarthy, Susan	ENSR
	x	x	Menzie, Charlie	MCA
x	x	x	Mickelson, Mike	MWRA
	x	x	Mitchell, David	ENSR
	x	x	Moore, Michael	WHOI
x	x	x	Pederson, Judy	MIT
x	x	x	Redlich, Susan	WWAC
	x	x	Rojko, Alice	DEP
	x	x	Rhoads, Don	SAIC
x	x	x	Schubel, Jerry	NEAq
	x	x	Schwartz, Jack	MDMF
x	x	x	Shine, Jim	Harvard
x	x	x	Studer, Marie	MCZM
x			Sung, Windsor	Sung Assoc.
x		x	Taylor, Craig	WHOI
x	x	x	Taylor, Dave	MWRA
	x	x	Testaverde, Sal	NMFS
x			Tomey, Dave	EPA
x			Trowbridge, Phil	MDPH
	x	x	Tucker, Jane	MBL
x	x	x	Wallace, Gordon	UMB
		x	Watling, Les	U Maine
x			Zavistoski, Becky	ENSR

APPENDIX B

Written Correspondence pertaining to Workshop

MARINE BIOLOGICAL LABORATORY

WOODS HOLE, MASSACHUSETTS 02543 • (508) 548-3705 • FAX: (508) 457-1548

THE ECOSYSTEMS CENTER

July 3, 1996

Dear Ken and Mike,

Sorry to take so long to get this to you. I sent copies of the overheads from my talk to ENSER as requested about two weeks ago. I hope that Jane will have a draft manuscript on the isotope work for you fairly soon. I also wanted to let you know that the manuscript we submitted to Estuaries on the Harbor benthic fluxes has been accepted with minor revisions. I will send you a copy of the revised manuscript as soon as we have it ready.

I had a few thoughts and comments on how benthic fluxes could continue to be useful for monitoring and on some other aspects of the benthic monitoring brought up at the workshop.

1)Bay monitoring -

I was very pleased to see how closely the 1995 data on oxygen uptake matched the 1993 and 1994 data. It appears that year to year variation in rates of SOD are on the order of 20% and that the seasonal pattern is quite reproducible. This suggests to me that SOD may be a very robust monitoring tool for measuring the effect of the outfall and that a change of as little as 50% may be " a measurable change". If all you are interested in is seeing is "affect" than you could probably get away with fewer than five measurements - perhaps only 2 or three measurements per year. However, the advantage of the five time points is that you can use it to calculate a carbon deposition rate. Because both SOD and carbon deposition are calculated by the HydroQual model it provides a nice check.

No mention was made of porewater sulfide values. In our study, Bay porewater sulfide values were almost never detectable while they were always detectable at depth in Harbor sediments. I think that the presence of dissolved sulfide would be a useful indicator. I realize that porewaters are somewhat of a pain. Eh could perhaps be a useful substitute but looking at the RPD or Eh 0 mV is is complicated by deep animal irrigation at some sites. However, we did find that the Bay Eh values almost never went below -100mV while the Harbor values at depth were typically -200 mV. If this pattern is holding perhaps this could be a useful indicator.

2) Harbor Fluxes

I don't think it is possible to conclude that Harbor fluxes have increased dramatically in the last year as the stations appear to all have been moved. According to Howes' monitoring plan, BH03 and BH08 have both been moved away from our locations. Brian characterized the move as "slight" which may not matter at BH03, however, he also stated that the carbon contents of all the stations were the same. We found carbon concentrations of 3-4.5 % at BH03. Station BH08 was in an erosional area and carbon contents of this sediment were typically an order of magnitude lower than at BH03. Although BH02 is supposed to be in the same location according to the monitoring plan the depth listed in his monitoring plan is shallower than where we sampled. We were sampling in an obvious depression and used both the GPS and the depth sounder to find the station. Also the carbon content of this station was considerably lower than BH03, and this wouldn't agree with his statement that the carbon contents of the sediments were similar.

I discussed moving the stations with Ken Keay a while back. Evidently at the time the argument was that our locations were not "representative". However, we did try to include a variety of sediment types and depositional environments. It is my belief that an important factor in the apparent large increase in SOD at some of these stations, especially BH08 where the year to year variation in respiration was very low, is due to the fact that several may have been moved from erosional and reworking environments into depositional areas. If these rates are representative, and if denitrification has also increased to such a large degree than you should be seeing changes in the chlorophyll and nutrients in transect from the Harbor.

I do agree that year to year variations in benthic animal abundance strongly effects sediment SOD, and the depth of the RPD. We discussed this at length in our reports and in our submitted manuscript. However, it may be premature to attribute the changes to a cessation in sludge discharge.

Hope all is well.

Sincerely,

Anne Giblin

Anne Giblin
Associate Scientist

APPENDIX C

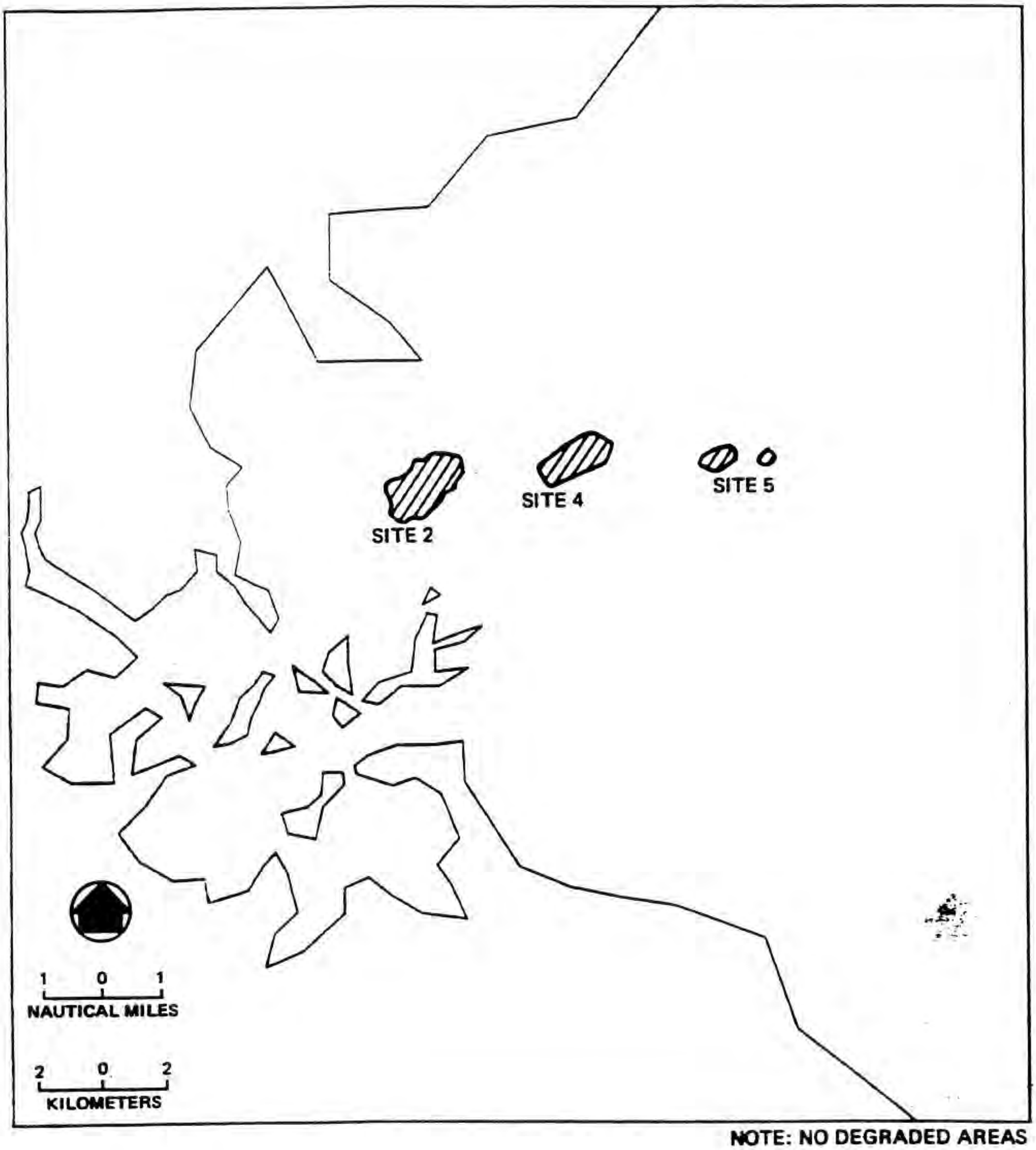
Overheads and Graphics from Presentations

APPENDIX C-1

Ken Keay
MWRA

TABLE 5.1.3.a SUMMARY OF AREAL EXTENT OF PREDICTED SEDIMENT ORGANIC ENRICHMENT

	Primary Treatment		Secondary Treatment	
	AREA DEGRADED (Km^2) (>1.5gC/m^2/d)	AREA CHANGED (Km^2) (0.1-1.5gC/m^2/d)	AREA DEGRADED (Km^2) (>1.5gC/m^2/day)	AREA CHANGED (Km^2) (0.1-1.5gC/m^2/day)
Non-Stratified Conditions				
SITE 2	0.8	16.9	0	3.0
SITE 4	0.02	13.7	0	1.9
SITE 5	0	10.4	0	0.6
Stratified Conditions				
SITE 2	2.2	32.7	0	4.9
SITE 4	1.2	18.9	0	3.2
SITE 5	0.05	12.2	0	3.1



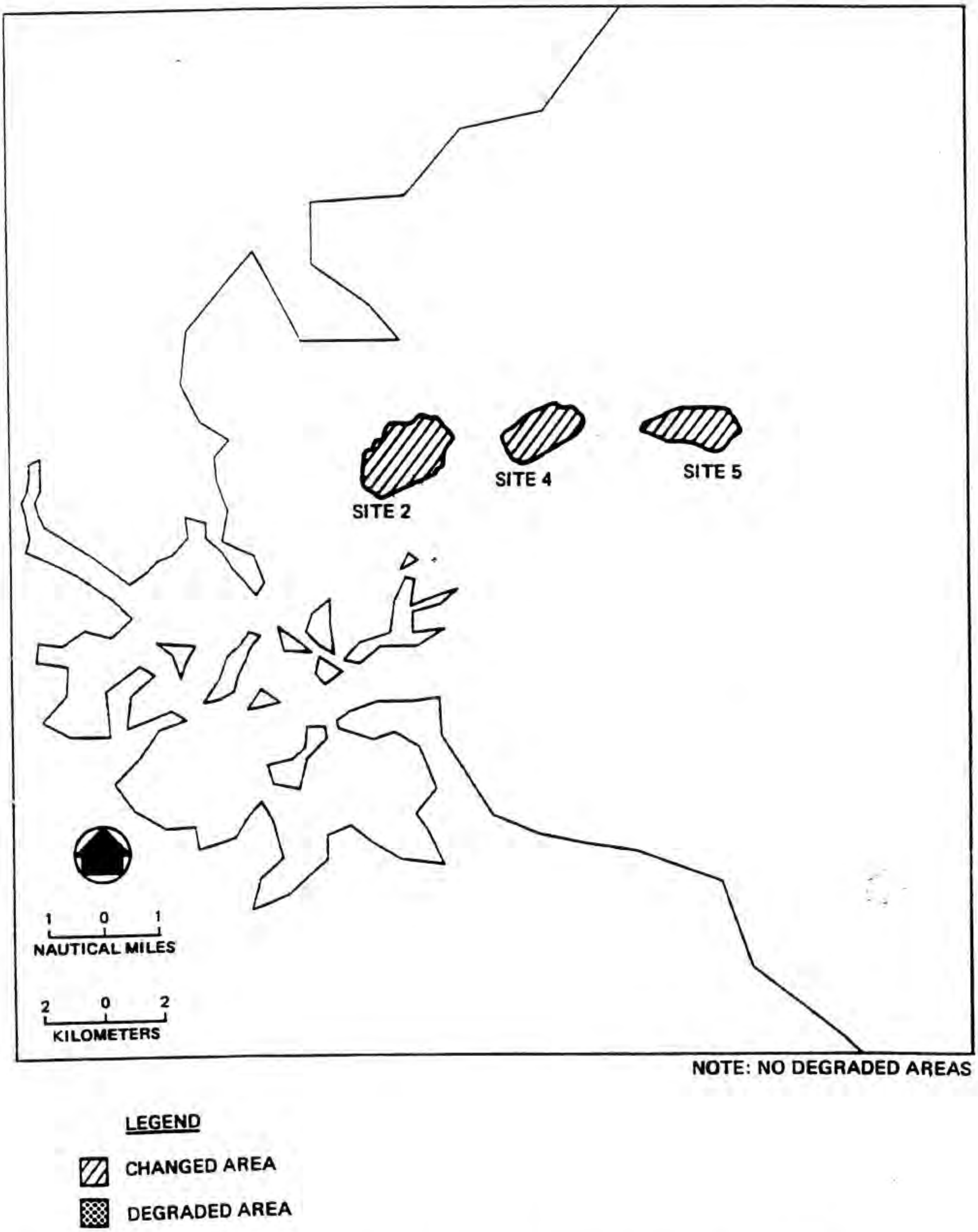
NOTE: NO DEGRADED AREAS

LEGEND

▨ CHANGED AREA

▦ DEGRADED AREA

FIGURE 5.1.3.d. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER NON-STRATIFIED CONDITIONS WITH SECONDARY TREATMENT FOR ALL SITES



NOTE: NO DEGRADED AREAS

FIGURE 5.1.3.b. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER STRATIFIED CONDITIONS WITH SECONDARY TREATMENT FOR ALL SITES.

concentrations than could be achieved by outfall relocation alone. Secondary treatment and outfall relocation provides an even greater measure of protection for Boston Harbor and the Bays' ecosystem.

7.3.4 Particulate Organic Carbon (POC) Flux

As has been described earlier, the flux of POC is an important variable because it acts as a food source to the benthic community. However, an excess of POC deposition can result in high sediment oxygen demand and have an adverse impact on the benthic community. Figures 7-22 and 7-23 present model computations of POC flux (J_{POC}) to the sediment for a five-day period in August for Massachusetts and Cape Cod Bays and for Boston Harbor and northeast Massachusetts Bay, respectively. These figures indicate that the highest fluxes of POC to the sediments are computed in Boston Harbor and the nearshore areas of Massachusetts Bay and western Cape Cod Bay. Within Boston Harbor the highest fluxes are computed in the western portions of the harbor, near the Neponset River. Model computations show the flux of particulate organic carbon to the sediment to be reduced in Boston Harbor under all three projection scenarios. However, the greatest reductions are found for those projections that involve outfall relocation. This is due to the fact that outfall relocation reduces DIN concentrations in the harbor and, therefore, reduces the production (and subsequent deposition) of algal biomass.

Outfall relocation without secondary treatment (upper right panel of Figure 7-23) results in an increase in POC deposition in the vicinity of the future outfall. Upgrading treatment of the MWRA effluent reduces the magnitude of the POC depositional flux at the future outfall site. This result occurs due to reduced levels of POC in the MWRA effluent that could be achieved under secondary treatment.

Figures 7-24 and 7-25 present temporal comparisons of J_{POC} for Boston Harbor and a number of nearfield and farfield stations in Massachusetts and Cape Cod Bays for the calibration and future outfall with secondary runs. Segment (6), in Figure 7-24, represents the actual outfall segment. As can be seen, the projection runs show significant

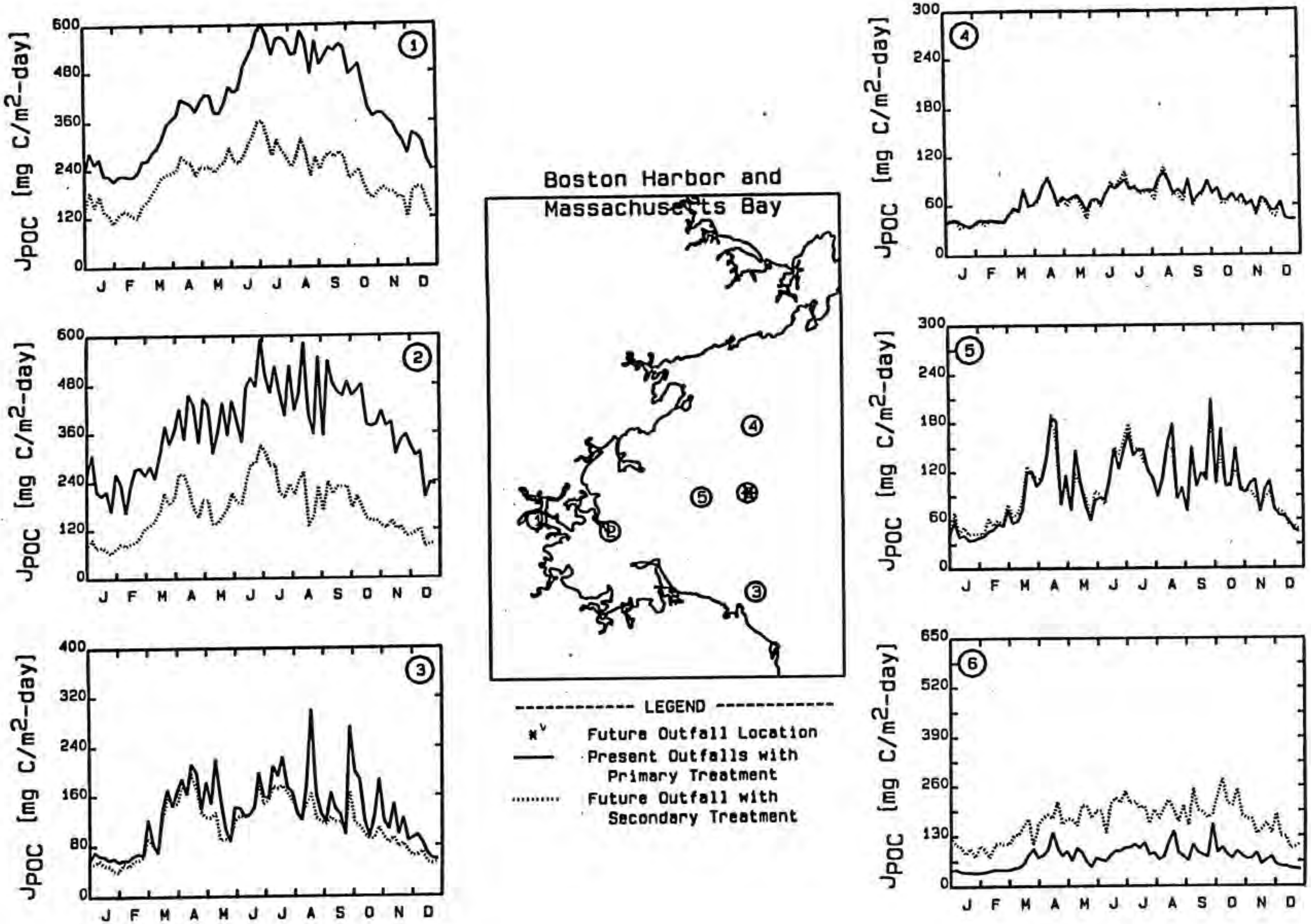


FIGURE 7-24. COMPARISONS OF NEARFIELD TEMPORAL CALIBRATION AND PROJECTION RESULTS FOR J_{POC} FLUX

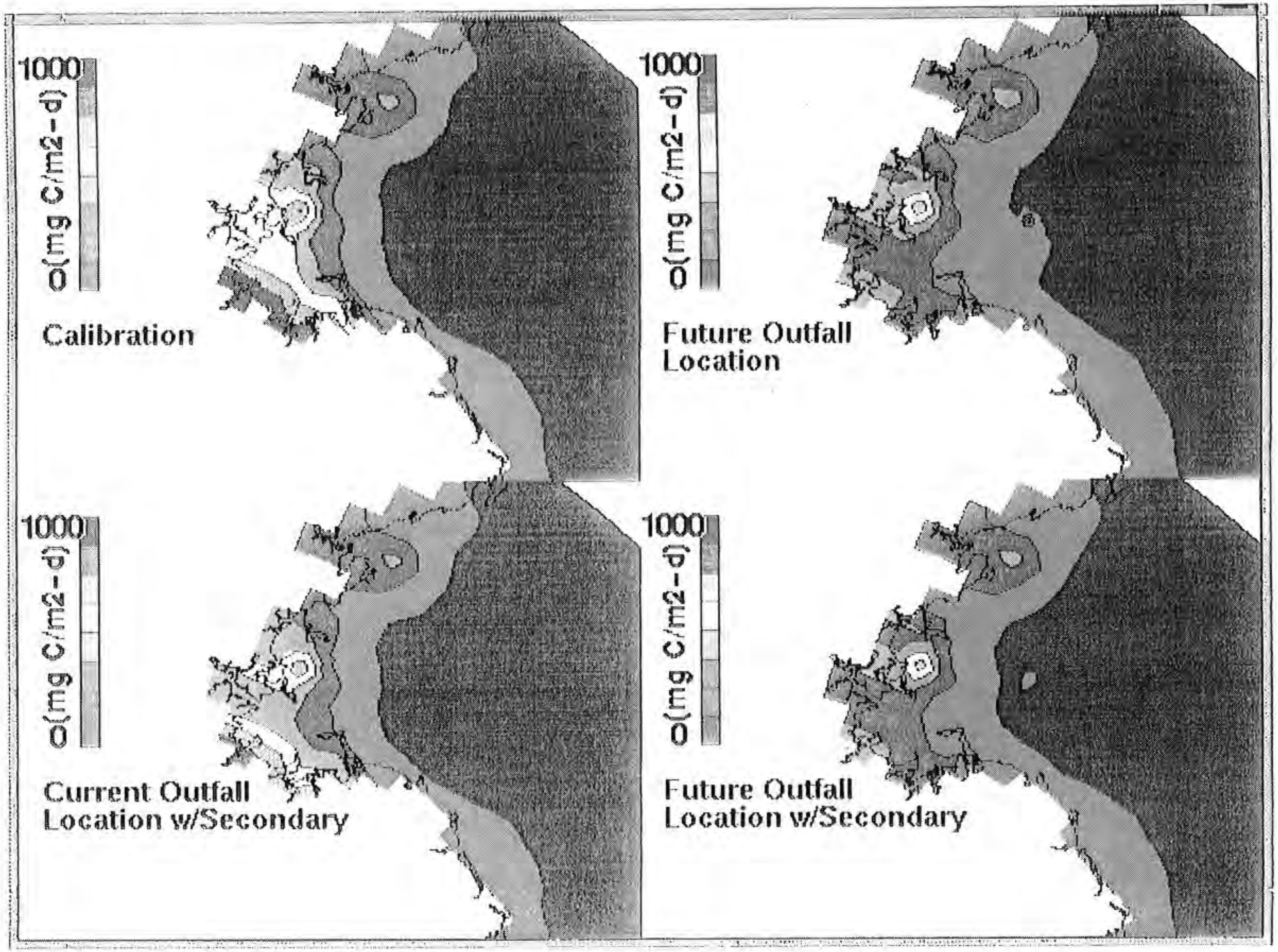


FIGURE 7-23. CALIBRATION AND PROJECTION RESULTS FOR NEARFIELD AUGUST POC FLUX

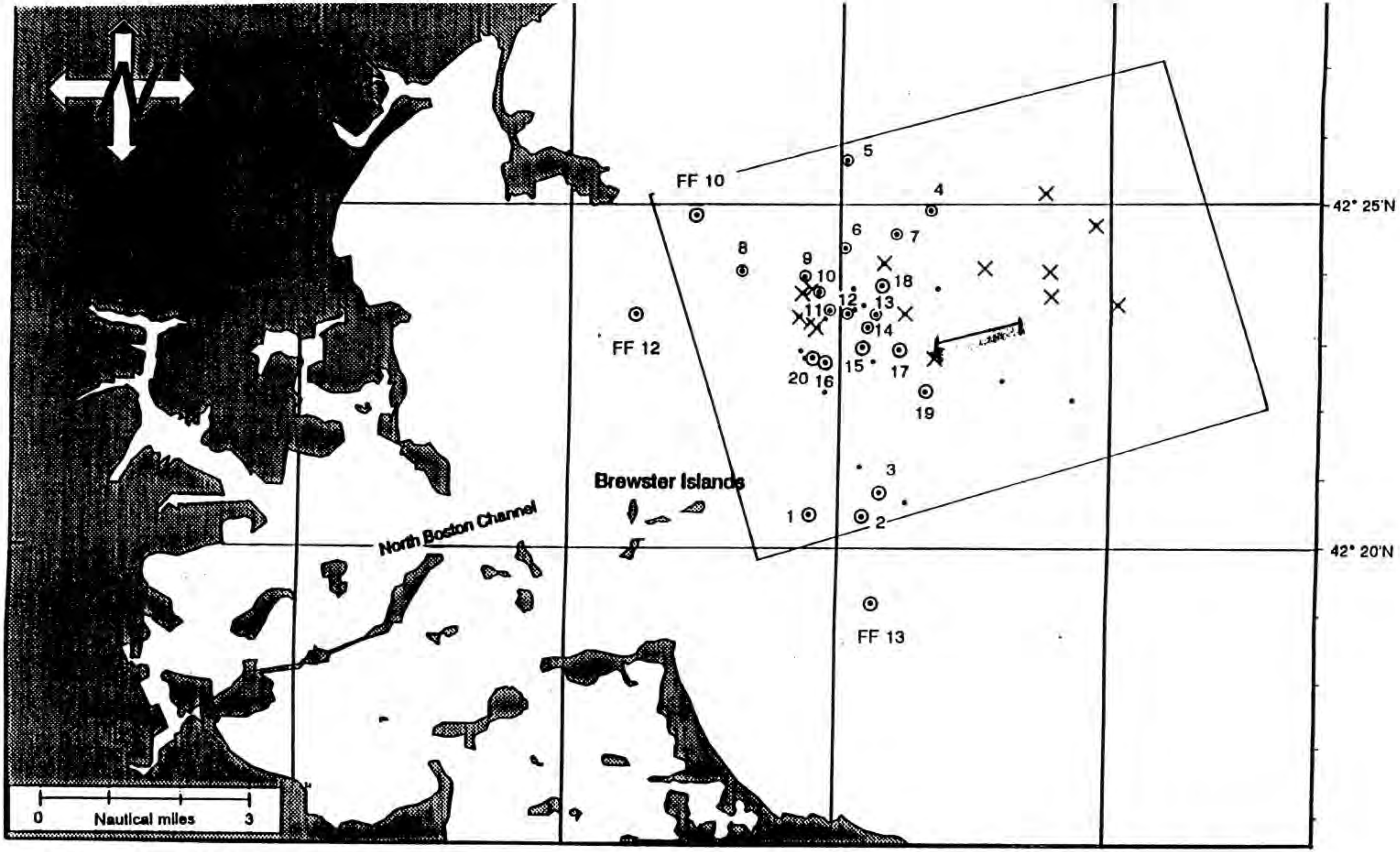


Figure 3. Nearfield Stations Occupied during the August 1992 Massachusetts Bay Nearfield Survey. Numbered donuts indicate the 20 nearfield stations where biology, chemistry, and sediments samples were collected in addition to the REMOTS® pictures. Small filled circles indicate REMOTS® stations that showed substrate unsuitable for sampling with a grab, or in a few cases, stations that were very close to completed stations where successful grabs were taken. Crosses mark stations where the grab was unable to collect sediment. Positions of three farfield stations (FF 10, 12, and 13) are included.

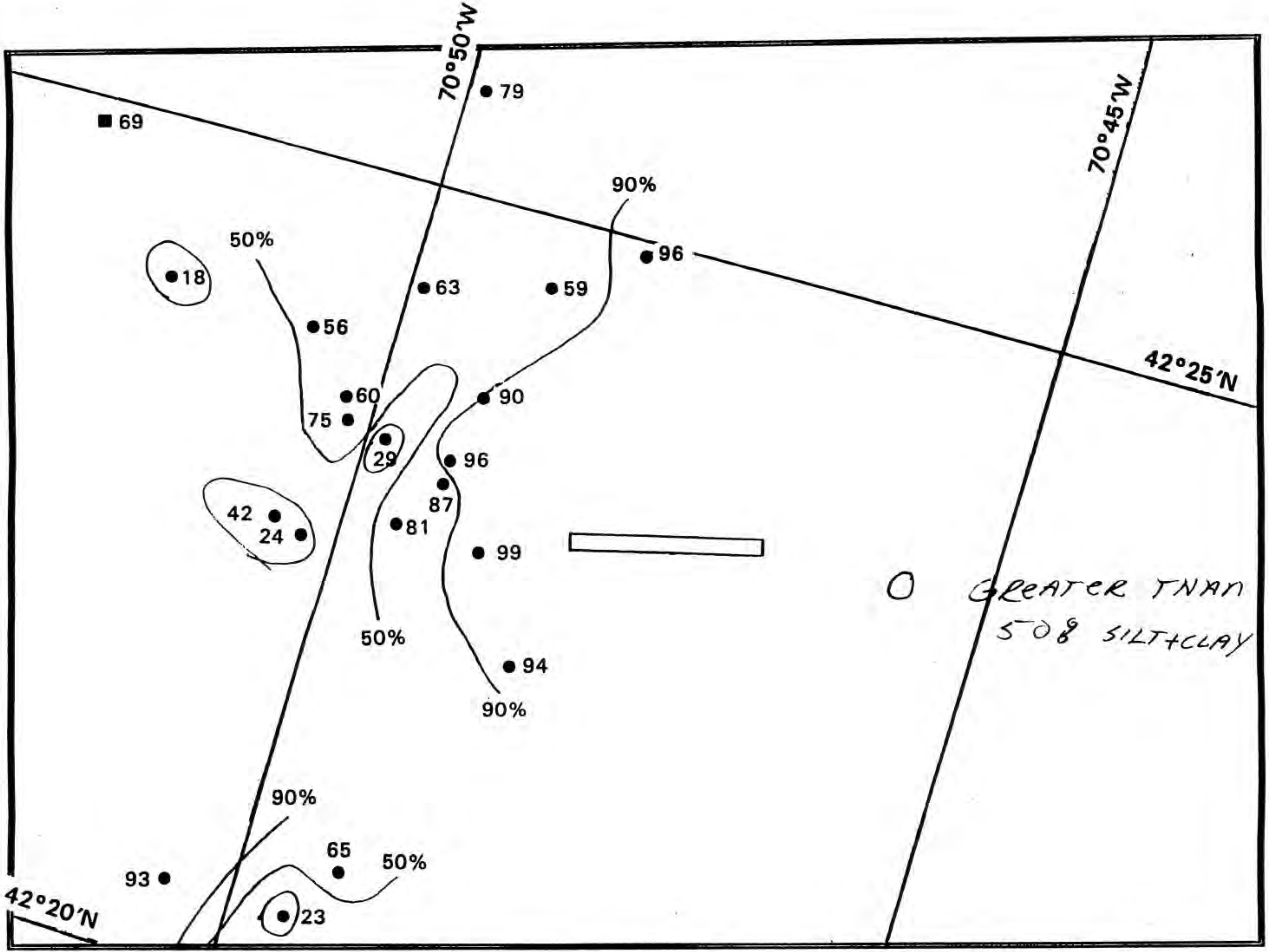
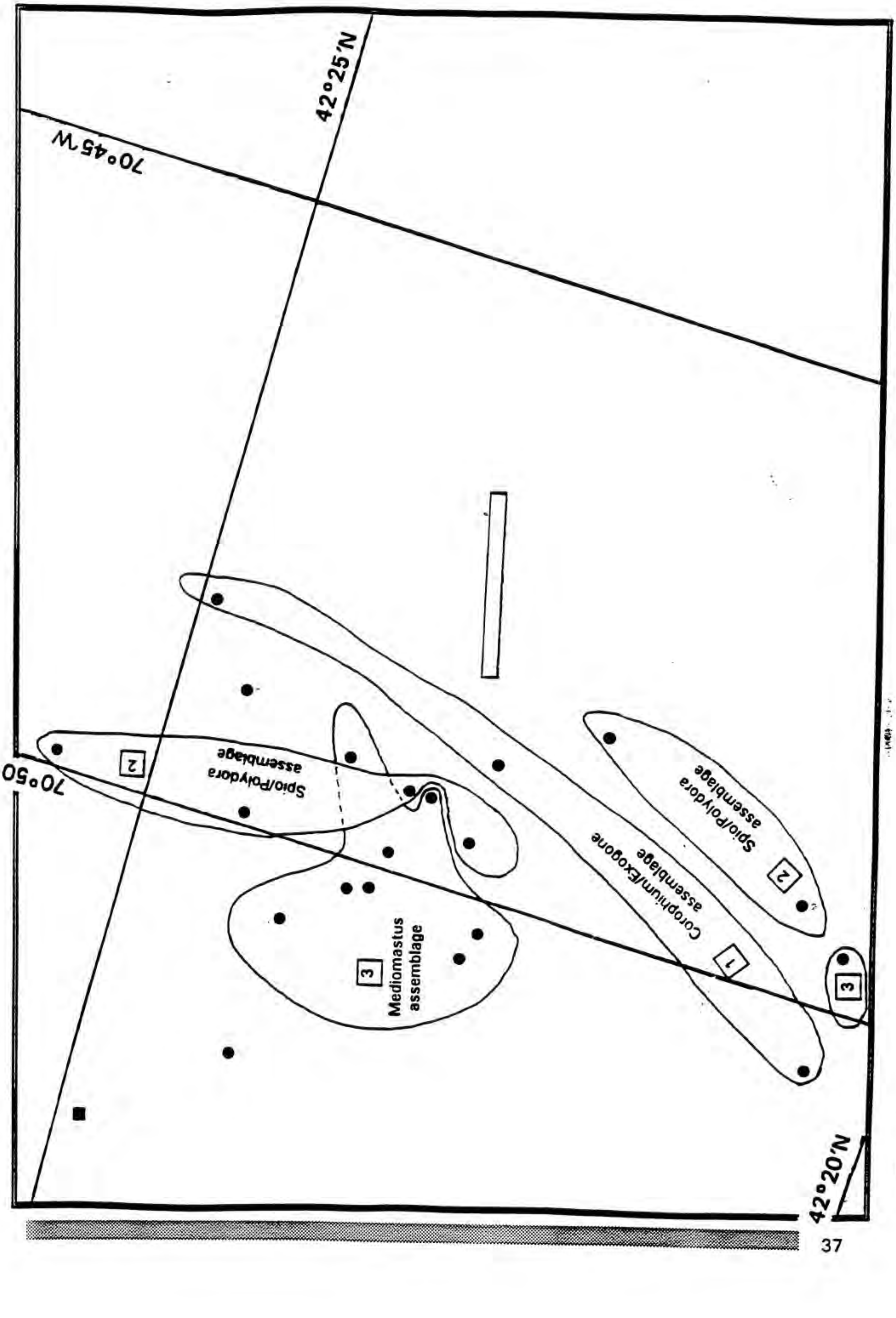


Figure 4. Distribution of Percent Sand and Gravel Contoured on the 50% and 90% Isopleths in the Nearfield.


42°25'N
70°45'W
70°50'W
42°20'N
2
Spio/Polydora assemblage
1
Corophium/Exogone assemblage
2
Spio/Polydora assemblage
3
Mediomastus assemblage
3

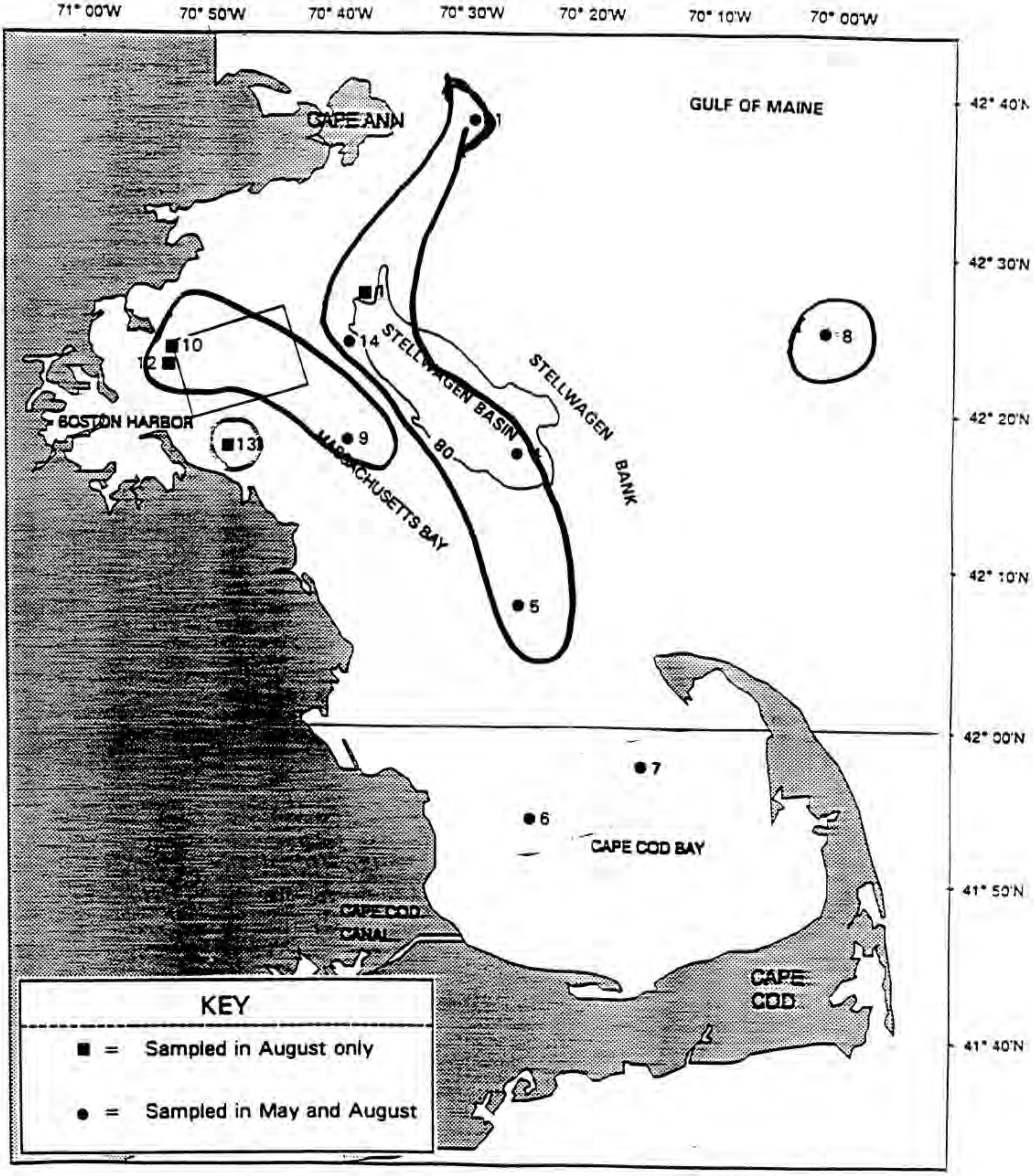


Figure 1. Location of Farfield Stations Sampled in May and August 1992. The rectangular box represents the nearfield area shown in detail in Figure 2.

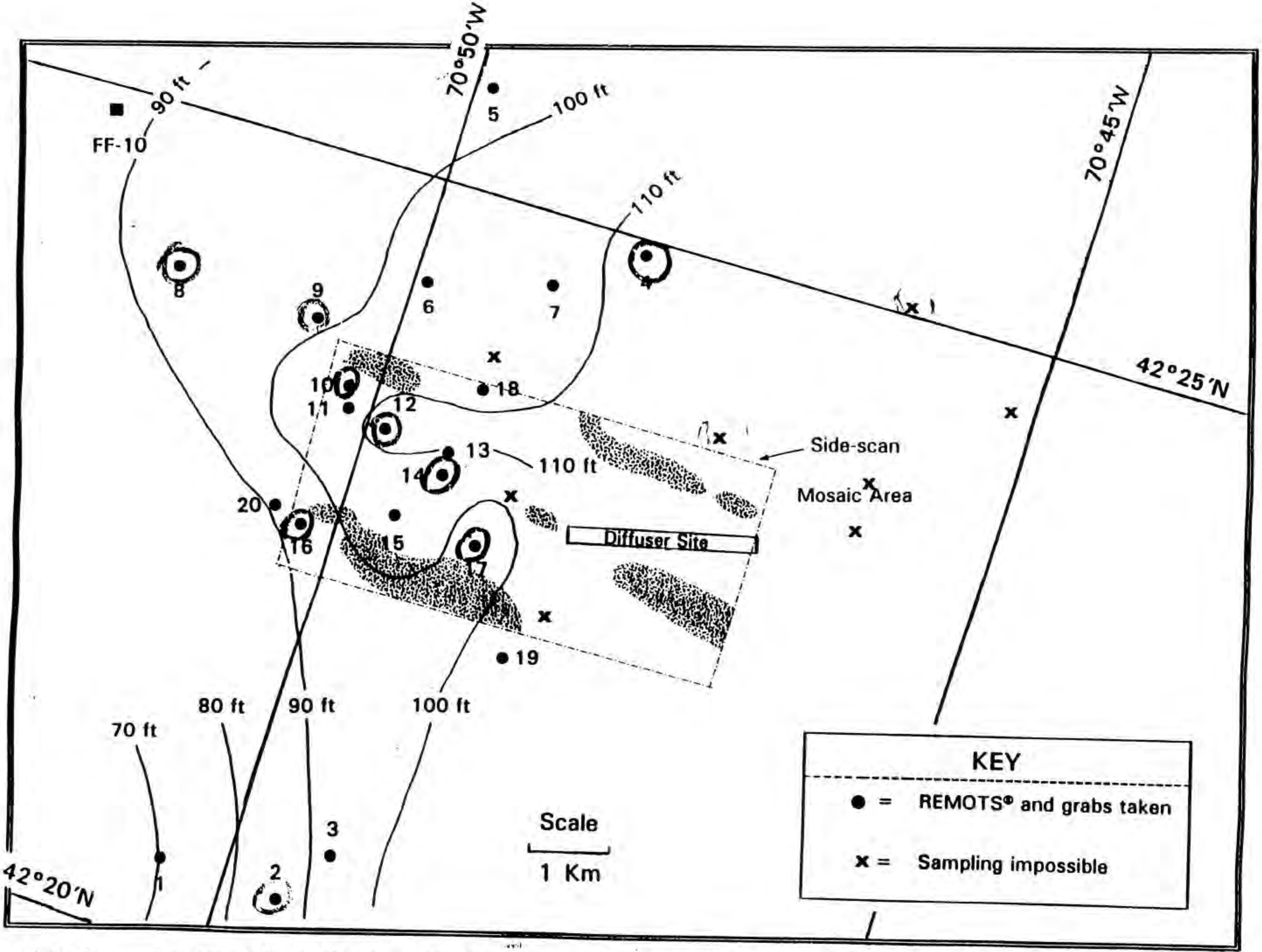


Figure 2. Locations of Nearfield Stations. Depth contours are in feet below MLW. Side scan mosaic area (dashed box) after Butman *et al.*, 1992. Shaded areas within the box are drumlins. Station FF10 has been included to facilitate contouring of data.

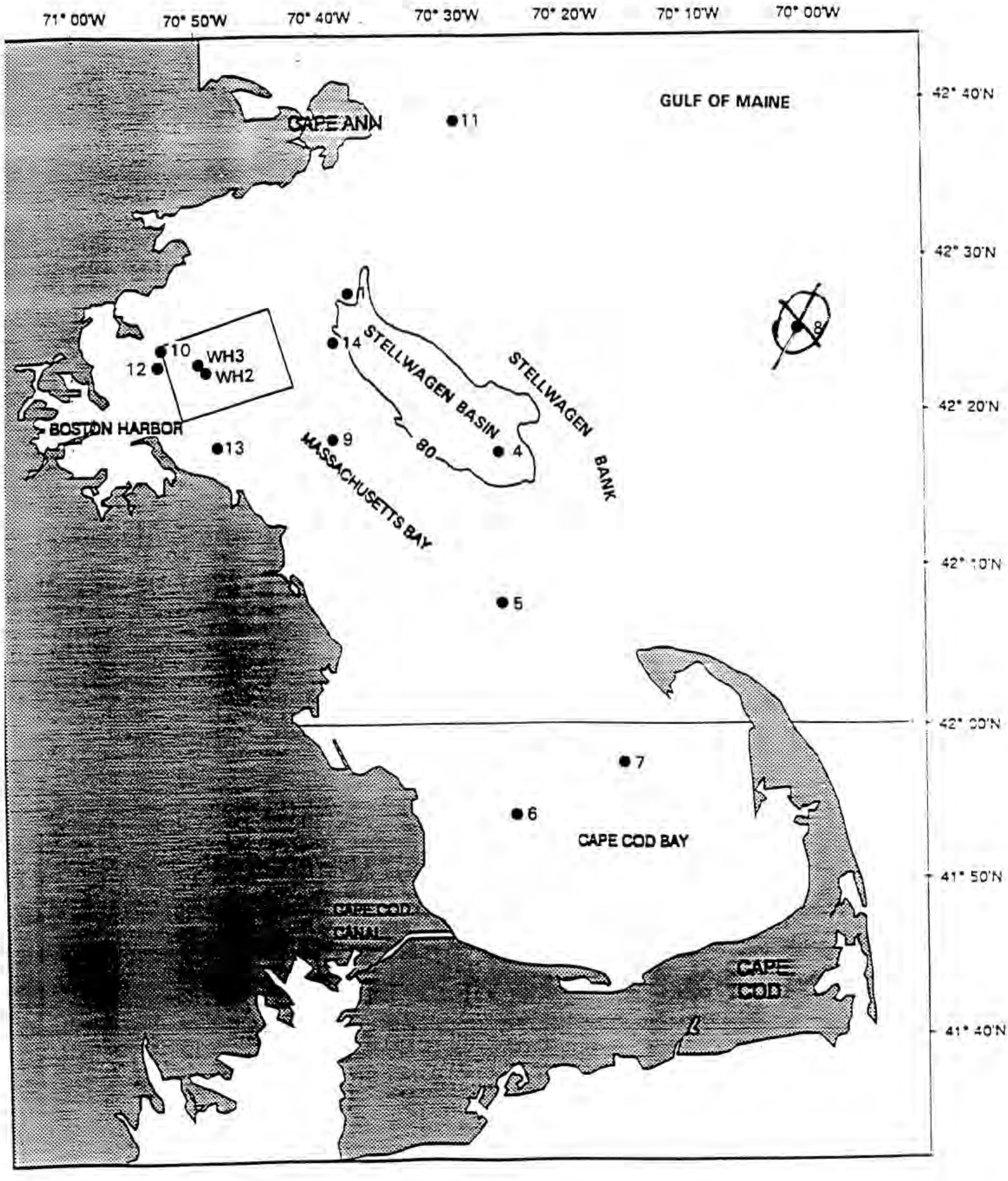
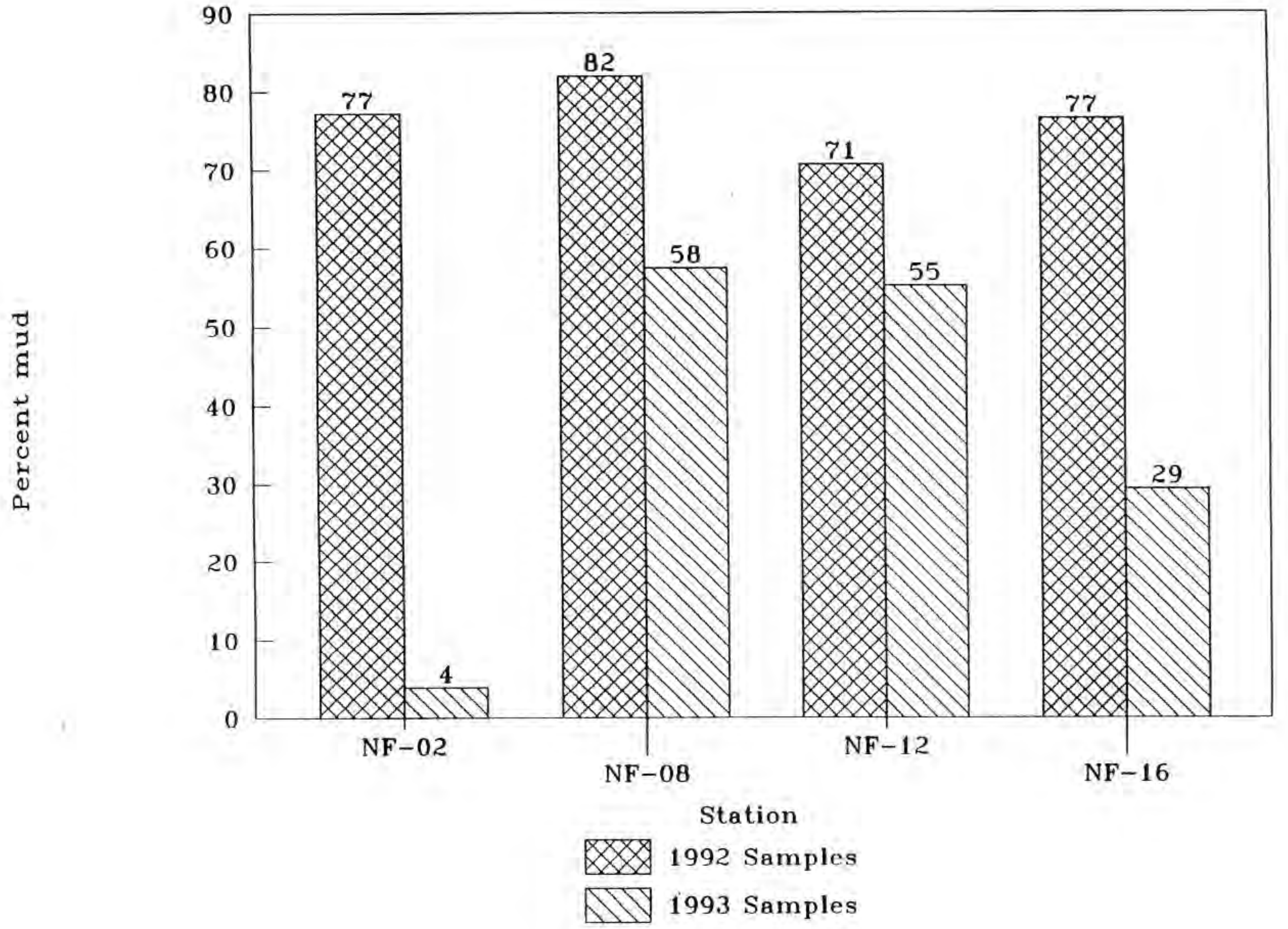


Figure 1. Location of Farfield Stations Sampled in May and August 1992. The rectangular box represents the nearfield area shown in detail in Figure 2.

Changes in sediment type, 1992–1993

Near-field stations



10 Most abundant species in selected near-field stations

August 1992 and August 1993 Sampling

Station NF-02

	Ranking	
Most Abundant taxa, 1992	1992	1993
Mediomastus californiensis	1	<10[1]
Asabellides oculata	2	<10
Aricidea catherinae	3	4
Hiatella arctica	4	1
Tubificoides apectinatus	5	<10
Polydora socialis	6	<10
Tharyx acutus	7	6
Spio limicola	8	<10
Prionospio steenstrupi	9	<10
Arctica islandica	10	<10

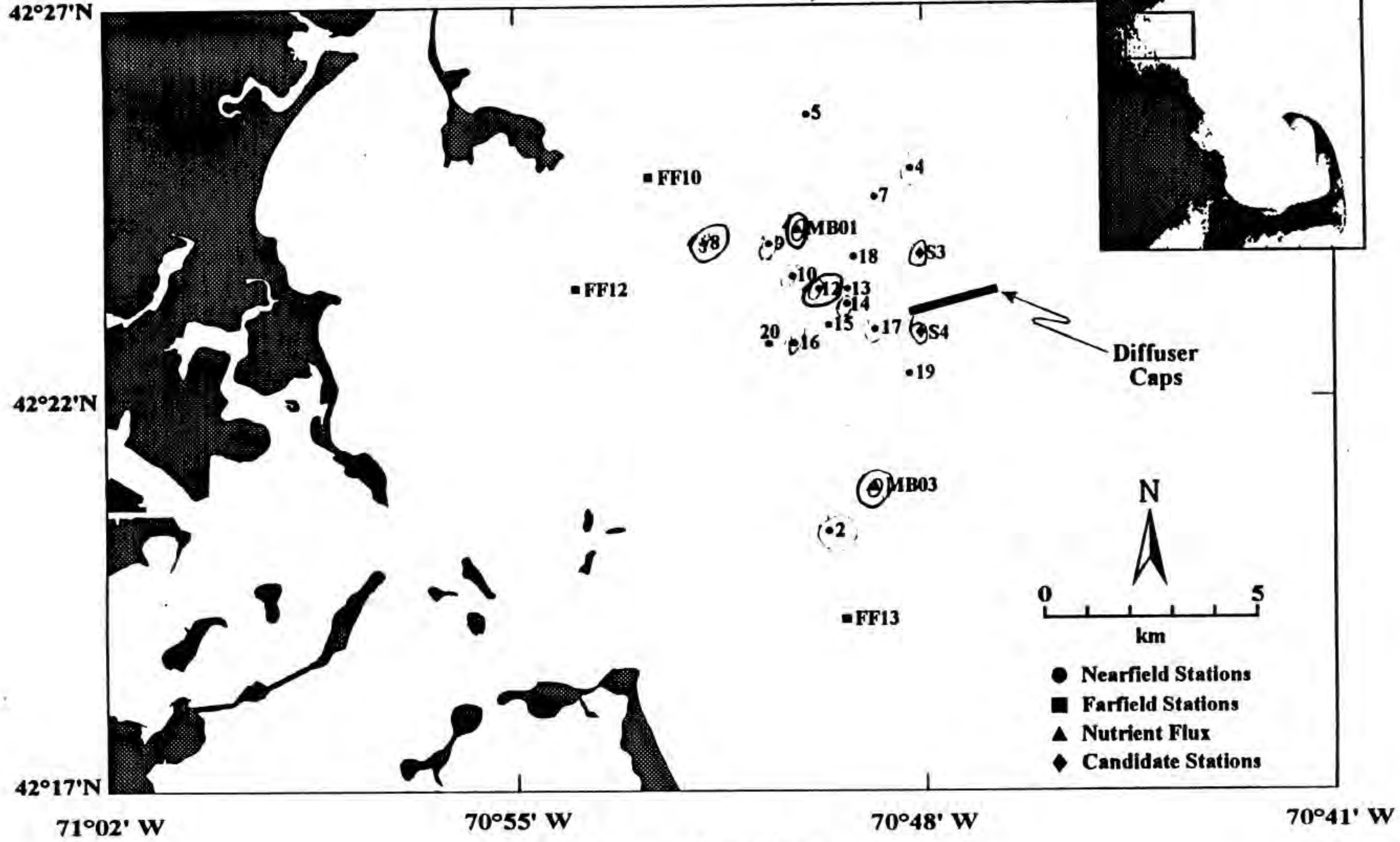
	Ranking	
Most Abundant taxa, 1993	1993	1992
Hiatella arctica	1	4
Bivalvia spp.	2	<10
Ophiura robusta	3	NF[2]
Aricidea catherinae	4	3
Phyllodoce mucosa	5	<10
Tharyx acutus	6	7
Mytilus edulis	7	<10
Cerastoderma pinnulatum	8	<10
Amphipoda sp. 1	9	NF
Spio thulini	10	NF

[1] Species present but not one of 10 most abundant

[2] Species not found at that station in 1992

10 Most abundant species in selected near-field stations		
August 1992 and August 1993 Sampling		
Station NF-12		
	Ranking	
Most Abundant taxa, 1992	1992	1993
Mediomastus californiensis	1	1
Spio limicola	2	3
Aricidea catherinae	3	2
Ninoe nigripes	4	5
Levinsenia gracilis	5	9
Prionospio steenstrupi	6	4
Leitoscoloplos acutus	7	7
Monticellina baptiste	8	6
Micrura spp.	9	<10
Nucula delphinodonta	10	<10
1993 taxa not in top 10 in 1992	1993	1992
Tharyx acutus	8	<10
Exogone verugera	10	<10

O→ NEW STATIONS
O→ COORDINATED W/ NUTRIENT FLUX



[illegible]

Figure 2. Nearfield Station Locations, S9403, August 1994

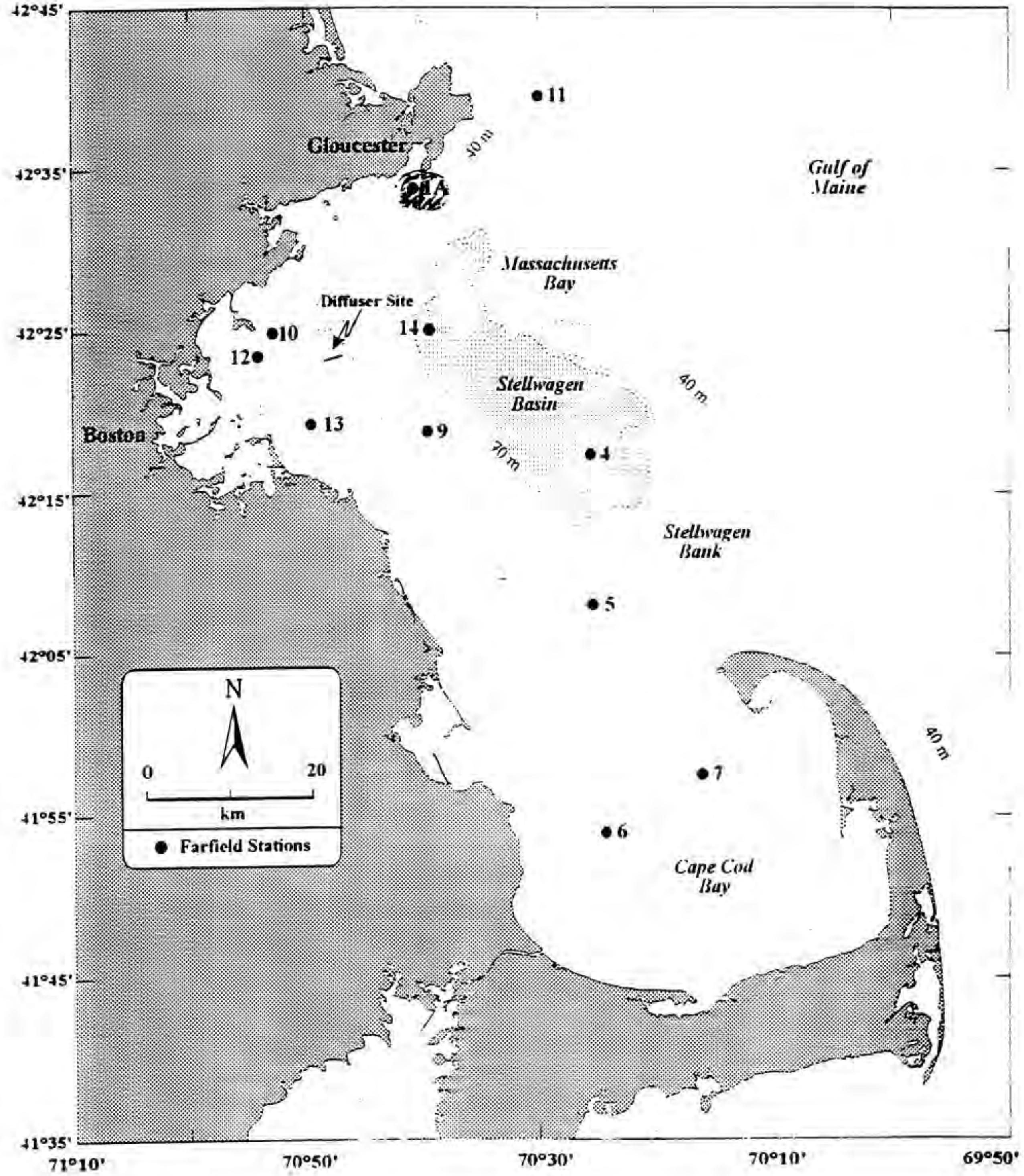


Figure 2. Farfield Station Locations, S9403, August 1994

MWRA BENTHIC MONITORING

	1992 sampling and analysis			
	Near-field		Far-Field	
	Biology	Chemistry	Biology	Chemistry
Number of stations	20		12	
Samples/Station	1	1	3	2
Total samples	20	20	36	24

	1993 sampling and analysis			
	Near-field		Far-Field	
	Biology	Chemistry	Biology	Chemistry
Number of stations	9		11	
Samples/Station	3	2	3	2
Total samples	27	18	33	22

	Ongoing benthic sampling and analysis			
	Near-field		Far-Field	
	Biology	Chemistry	Biology	Chemistry
Number of stations	3		11	11
Samples/Station	3	2	3	2
Number of stations	17			
Samples/Station	1	1		
Total samples	26	23	33	22

COATS (1995) SEDIMENT CHEMISTR

Box model

SIZE OF BOX:

2 cm x All Depositional Sediments w/in 2 Km of OUTFAll.

INPUT TERMS

10% OF CONTAMINANT LOADINGS EXPECTED FROM SECONDARY DISCHARGE.

OUTPUT TERMS: NONE

BASELINE CONCENTRATIONS: 1994 DATA

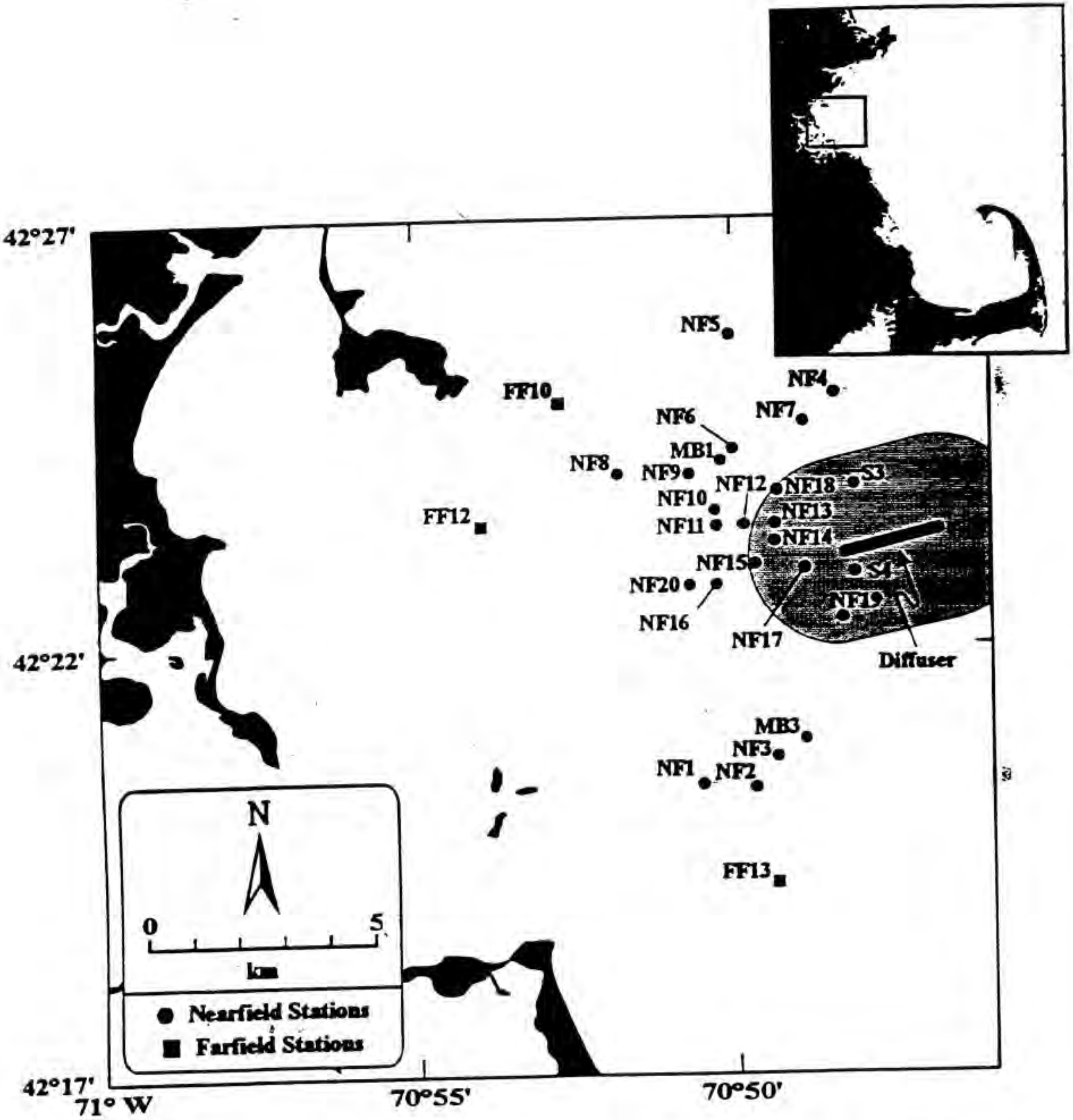


Figure 4. Location of near and farfield stations at midfield distances from the diffuser. The shaded area is the locus of points at a 2 km distance from the outfall. The inset shows the midfield study area location within Massachusetts and Cape Cod Bays.

Sediment Contaminants

Baseline, Detectable Change, Possible Thresholds

Contaminant	Baseline Average	Detectable Increase	Thresholds		Minimum years to detect		
			PEL	90% ERM	Increase	PEL	90% ERM
Cadmium(ppm)	0.05	0.1	4.21	8.64	1.1	94	195
Copper(ppm)	15	24	108	243	6.5	68	167
Mercury (ppm)	0.12	0.22	0.7	0.64	18	105	94
Total DDTs(ppb)	0.8	2.3	51.7	41.5	>1,000	>1,000	>1,000
Total PCBs(ppb)	7.9	14.5	188.8	162	>1,000	>1,000	>1,000
Total PAHs (ppb)	2061	4395	16771	40313	>1,000	>1,000	>1,000

All Information from Tables 8 and 9, and Section 3 of Coats (1995), MWRA Enquad tech report 95-20

Baseline average" are the average concentrations in all samples taken in 1994 within 2 km of the future outfall

Detectable increase" are the levels at which increase over the baseline average could be detected

Thresholds: PEL's are the Probable Effects Levels of MacDonald (1993), 90% of Effects Range, Medium of Long et al. (1995)

Years to detect are predicted from a conservative box model of contaminant build-up in soft sediments w/in 2 km of outfall.

Benthic and Sediment Monitoring

Perturbations of concern: R4, R6, R8, R12, R13

Hypotheses/Warning Levels		**Action Levels**
B1	Mean benthic diversity at near-field muddy stations will not halve (decrease to one-half of that measured during the baseline monitoring).	
B2	Benthic diversity at near-field sandy stations will not halve.	
B3	Mid-field (stations 2-7 km from the discharge) benthic diversity will not show a show a significant downward trend measured over any three consecutive post-discharge years.	
B4	The composition of mid-field soft-bottom communities will not change to one typical of a degraded benthic community.	
Alt B1	The species composition and relative abundance patterns of communities at stable mid-field soft-bottom sites will not significantly depart from those measured during the baseline monitoring period.	

Measurement Program		**Speaker**
B1-B4	Annual mid-summer sampling at 20 sites in near-field, 11 in far-field. Analyses for infaunal composition, abundance, and explanatory parameters (e.g. grain size, TOC, contaminants).	Jim Blake, Brigitte Hilbig
Alt B1	As above.	
	Supporting study, annual survey of rocky bottom environments in the near-field.	Barbara Hecker

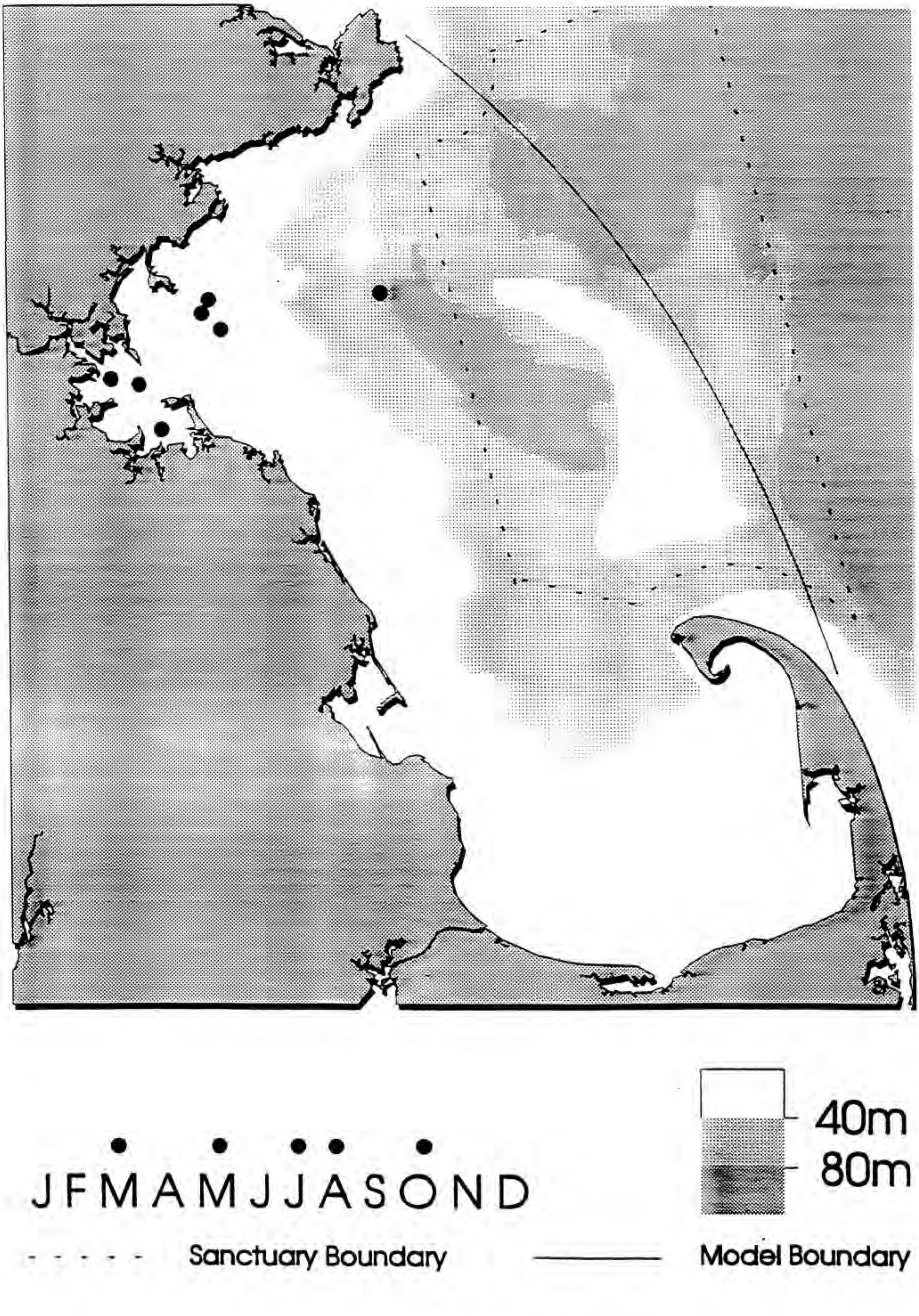
Benthic and Sediment Monitoring

Perturbations of concern: R4, R6, R8, R12, R13

Hypotheses/Warning Levels		Action Levels
B5	The mean depth of sediment RPD at muddy near-field stations will not halve (decrease to 50% of the average measured during baseline monitoring).	
B6	RPD depth will not decrease by more than 20% per year, measured over 3 consecutive post-discharge years.	
B7	Sediment contaminant concentrations at mid-field (2-7 km from outfall) stations will not exceed 90% of NOAA ER-M values.	
B8	Sediment contaminant concentrations at mid-field stations will not exceed 90% of available EPA sediment criteria	Exceed criteria

Measurement Program		Speaker
B5, B6	Annual mid-summer sampling at 20 sites in near-field, 11 in far-field. Measurement of apparent RPD depth in sediments.	Don Rhoads
Alt B5, B6	Midsummer Sediment Profile Imaging (SPI) at 20 NF sites. Measurement of apparent RPD depth from SPI images.	Don Rhoads
Alt B5, B6	Supporting study, Seasonal measurements of nutrient fluxes, eH profiles and apparent RPD in near-field and Harbor muddy sediments	Brian Howes
B7,B8	As B5, B6 above. Analysis of sediment samples for trace and major metals, PAHs, PCBs, pesticides, sewage tracers, TOC, and grain size.	Gordon Wallace, Eric Butler
	Ongoing U.S.G.S. supporting studies of sedimentary regimes, sediment resuspension, high frequency sediment coring and geochemical analysis at 2 near-field sites.	Mike Bothner.

Sediment-water Flux Monitoring



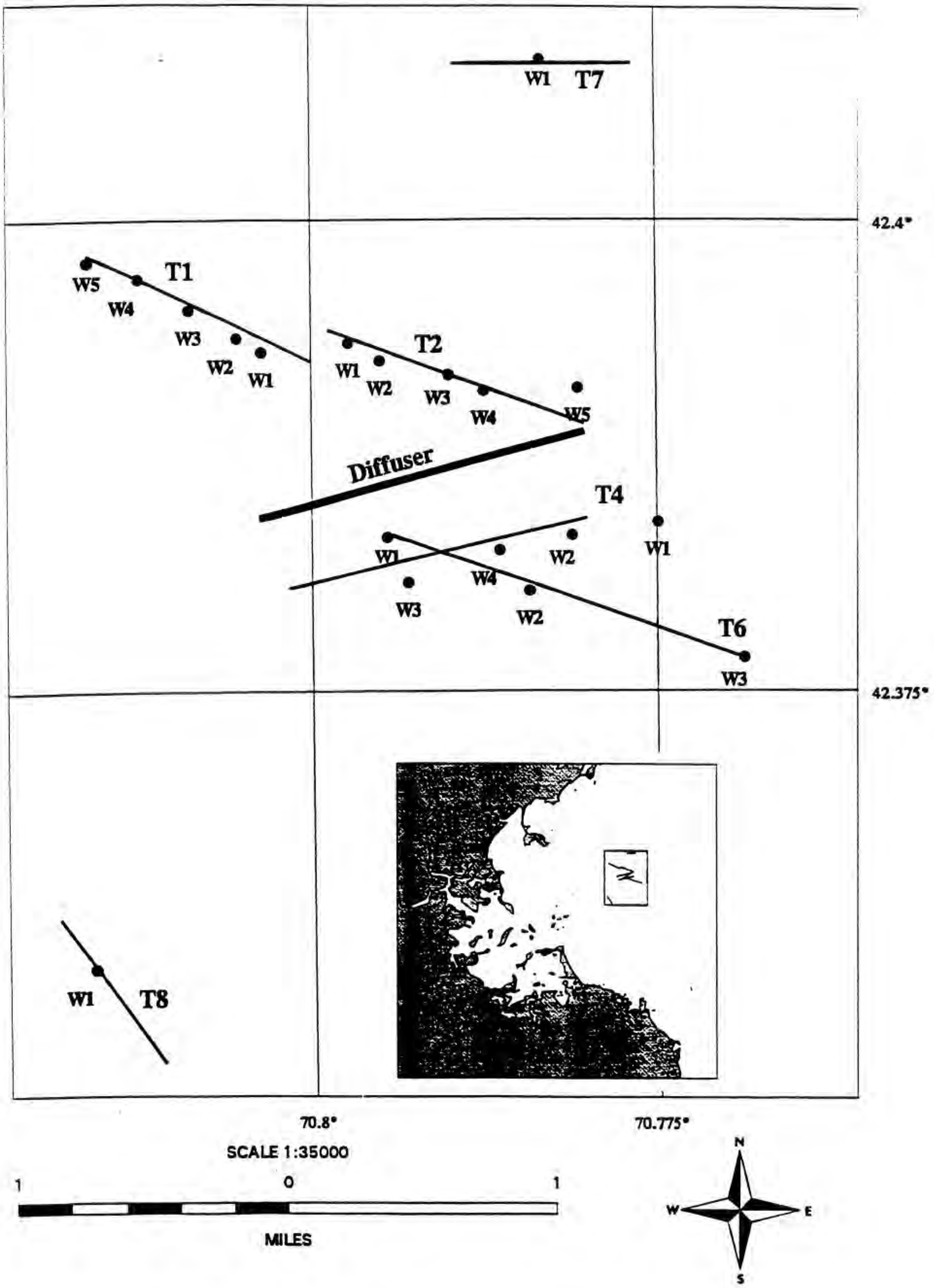


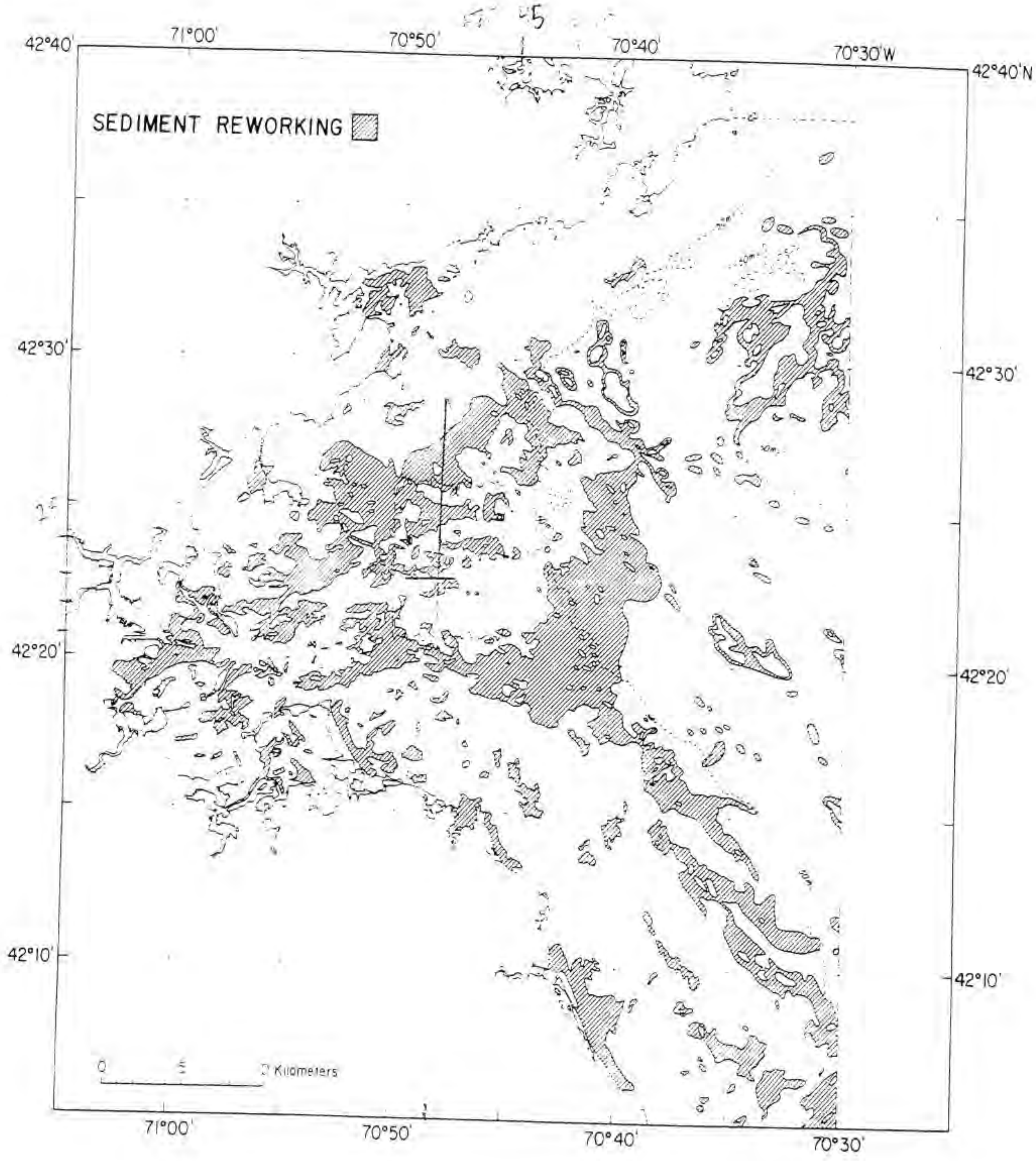
Figure 1. Location of transects and waypoints, Nearfield Hardbottom survey, June 1995.

APPENDIX C-2

Donald Rhoads

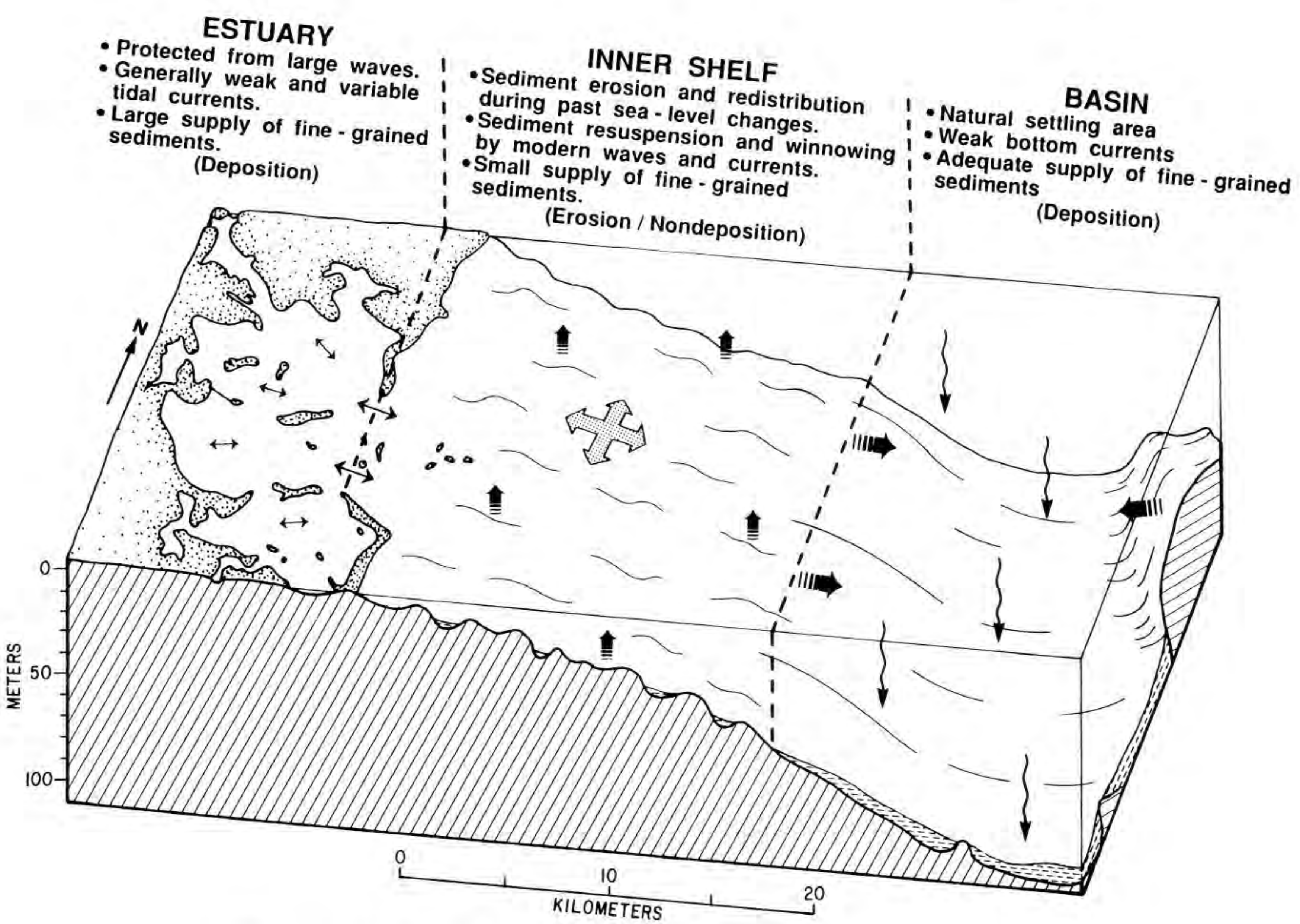
Fig 1

FIG.11



42°40'
71°00'
70°50'
70°40'
70°30'W
42°40'N
SEDIMENT REWORKING ▨
42°30'
42°30'
42°20'
42°20'
42°10'
42°10'
0
5
Kilometers
71°00'
70°50'
70°40'
70°30'

fig 2



From Knebel & Circe

FIG.12

fig 3

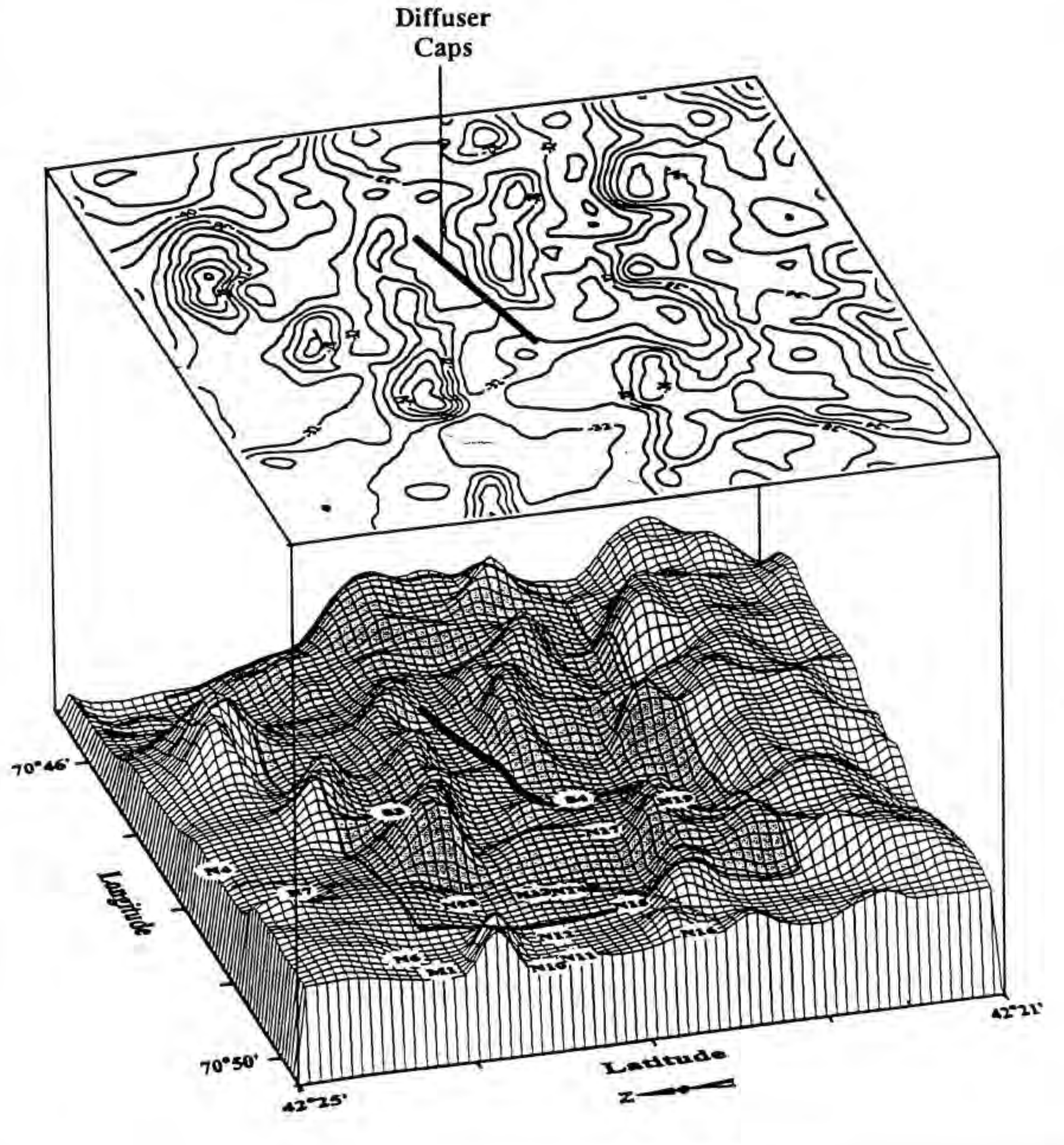
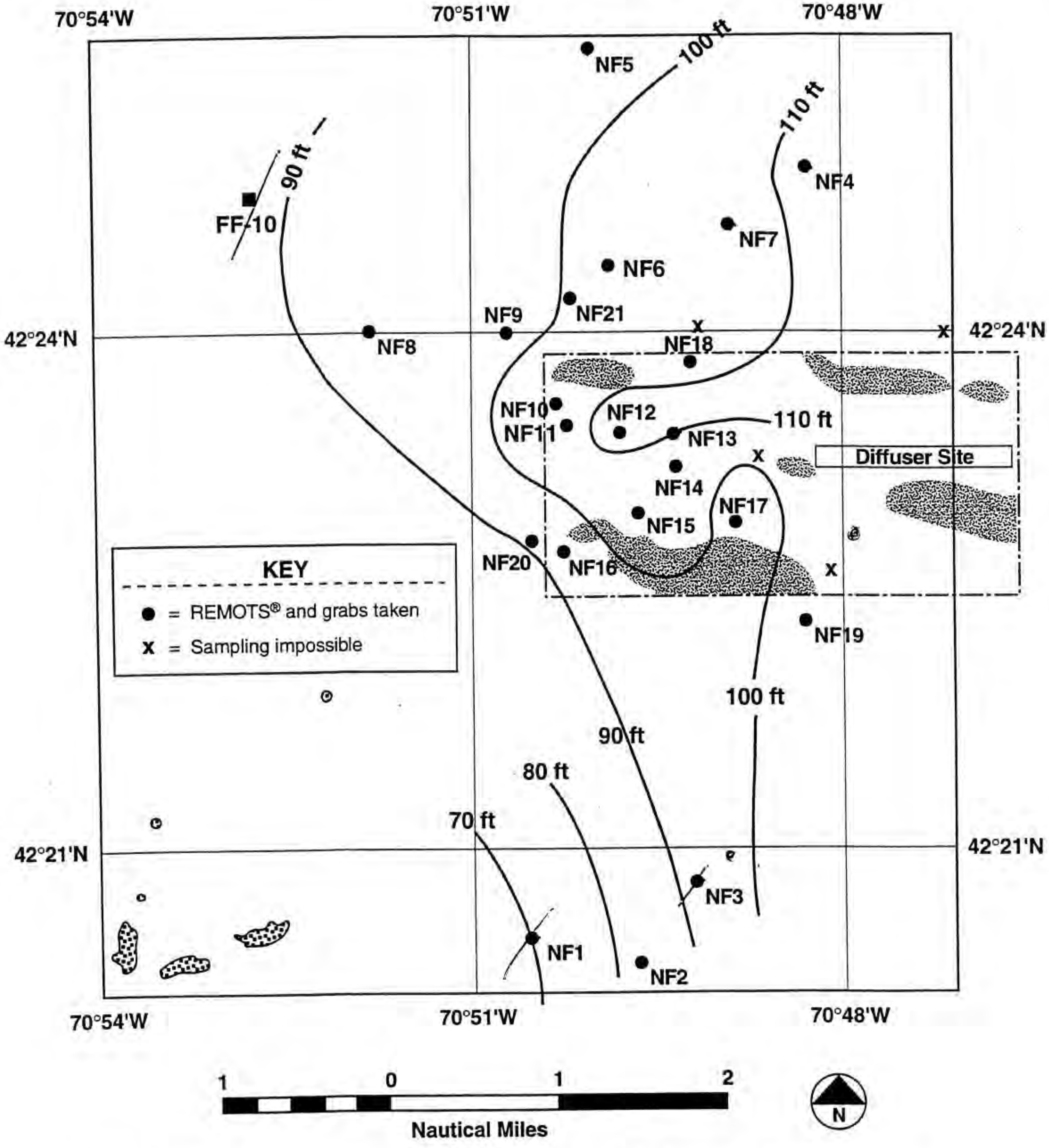


Figure 2. High-resolution bathymetry (meters) surrounding the diffuser caps as determined by Bothner *et al.*, 1992. Shading on the surface (lower) map delineates a 2-km region surrounding the diffuser. Station locations are labeled on the surface map where the prefix "N" indicates a nearfield station.

fig 4

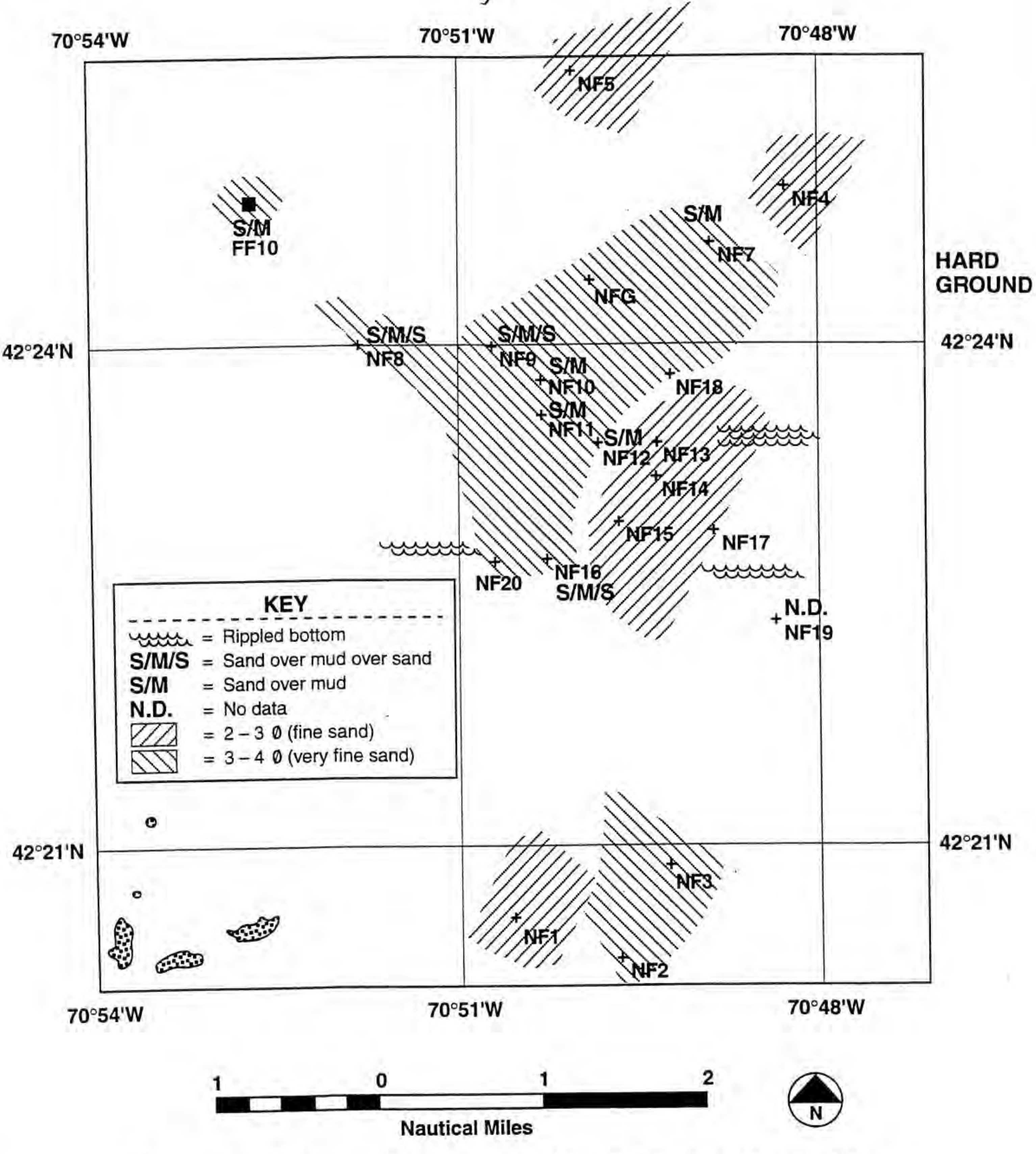


1992 Location of Nearfield Stations. Depth contours are in feet below MLW. Side-scan mosaic area (dashed box) after Butman *et. al.*, 1992. Shaded areas within the box are drumlins. Station FF10 has been included to facilitate contouring of data.

'92 22 STA

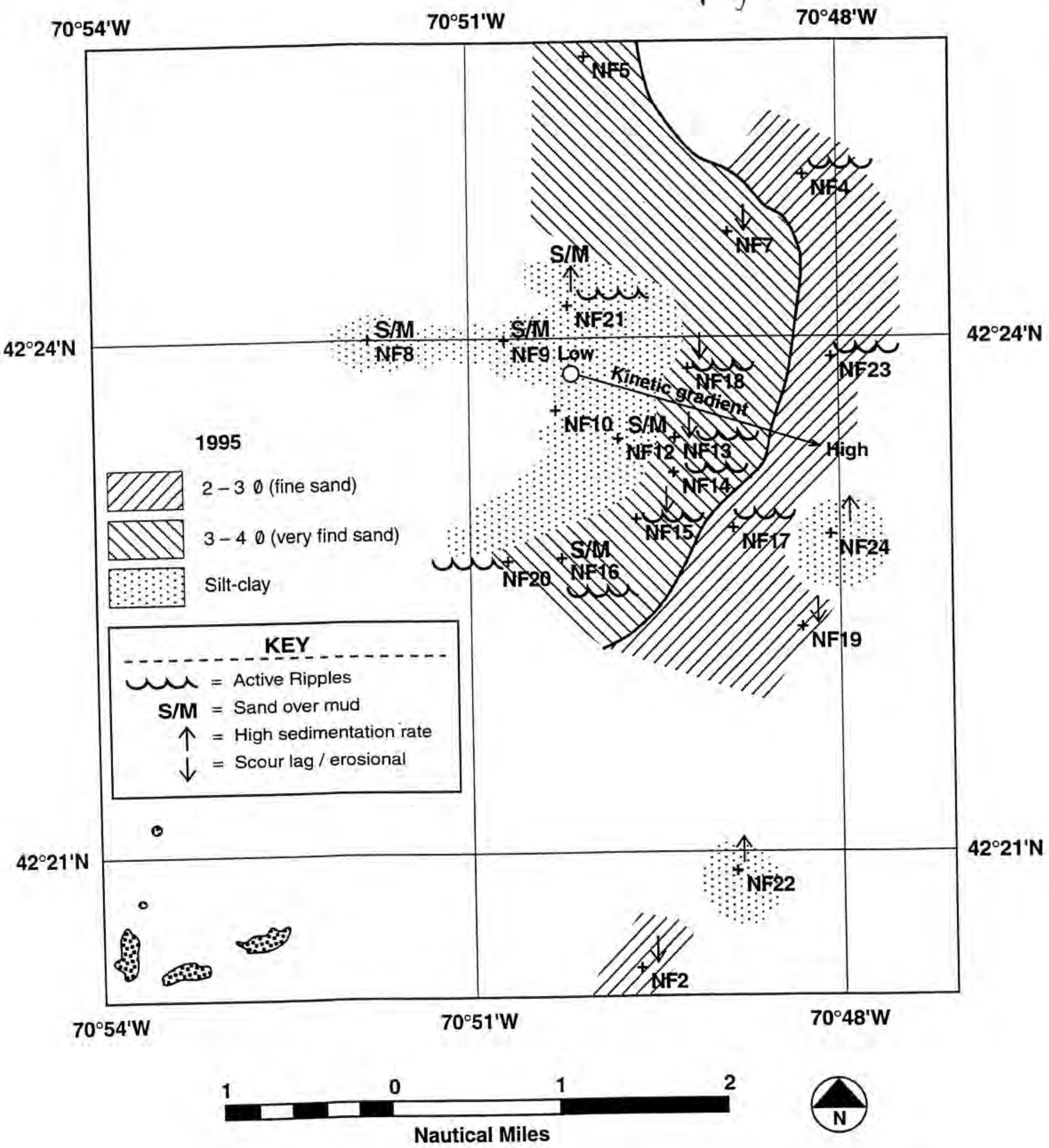
95

fig 5



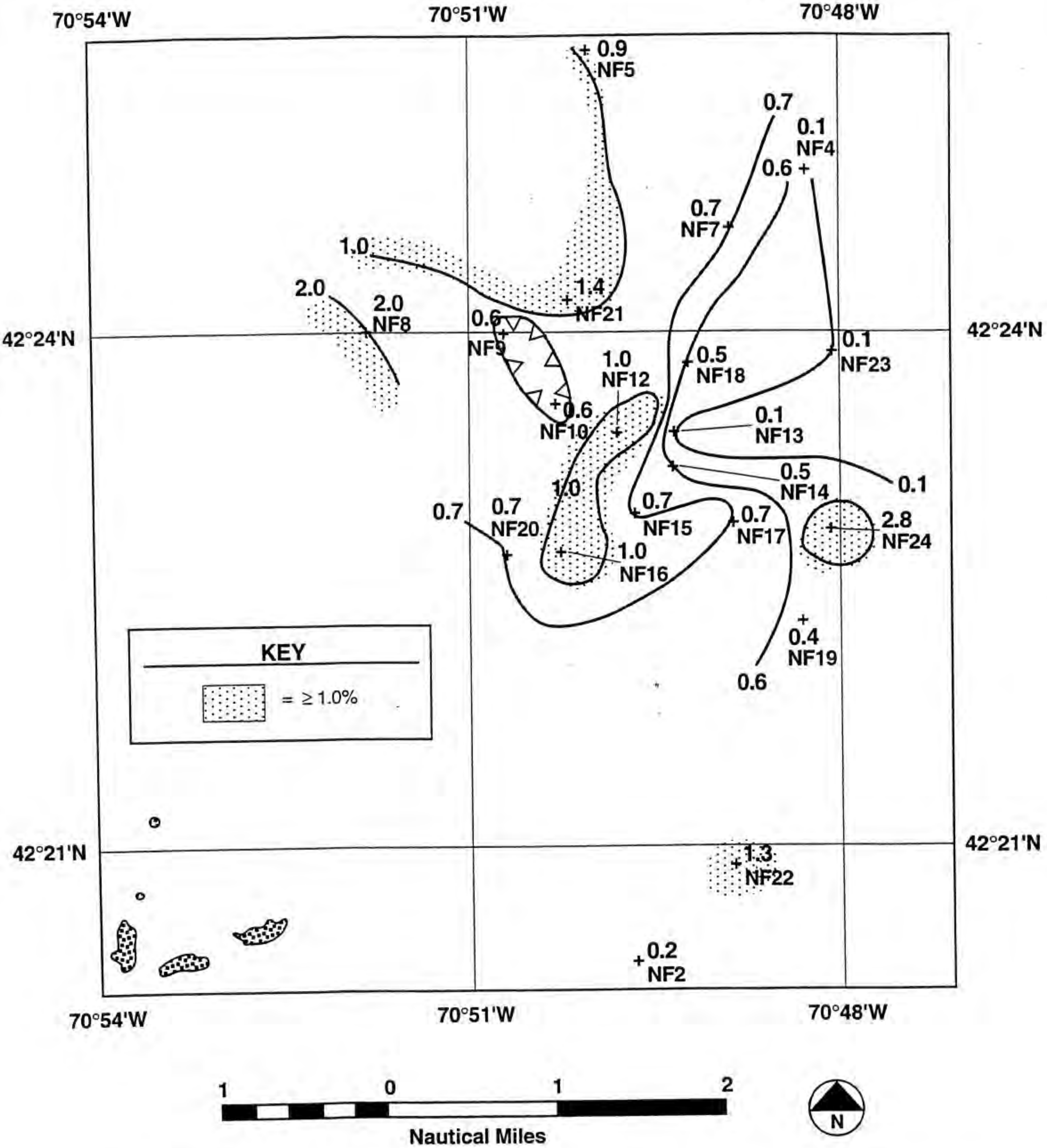
1992 Distribution of Major Modal Grain Size and Other Sedimentary Features in the Nearfield. Data are from REMOTS® images.

fig 6



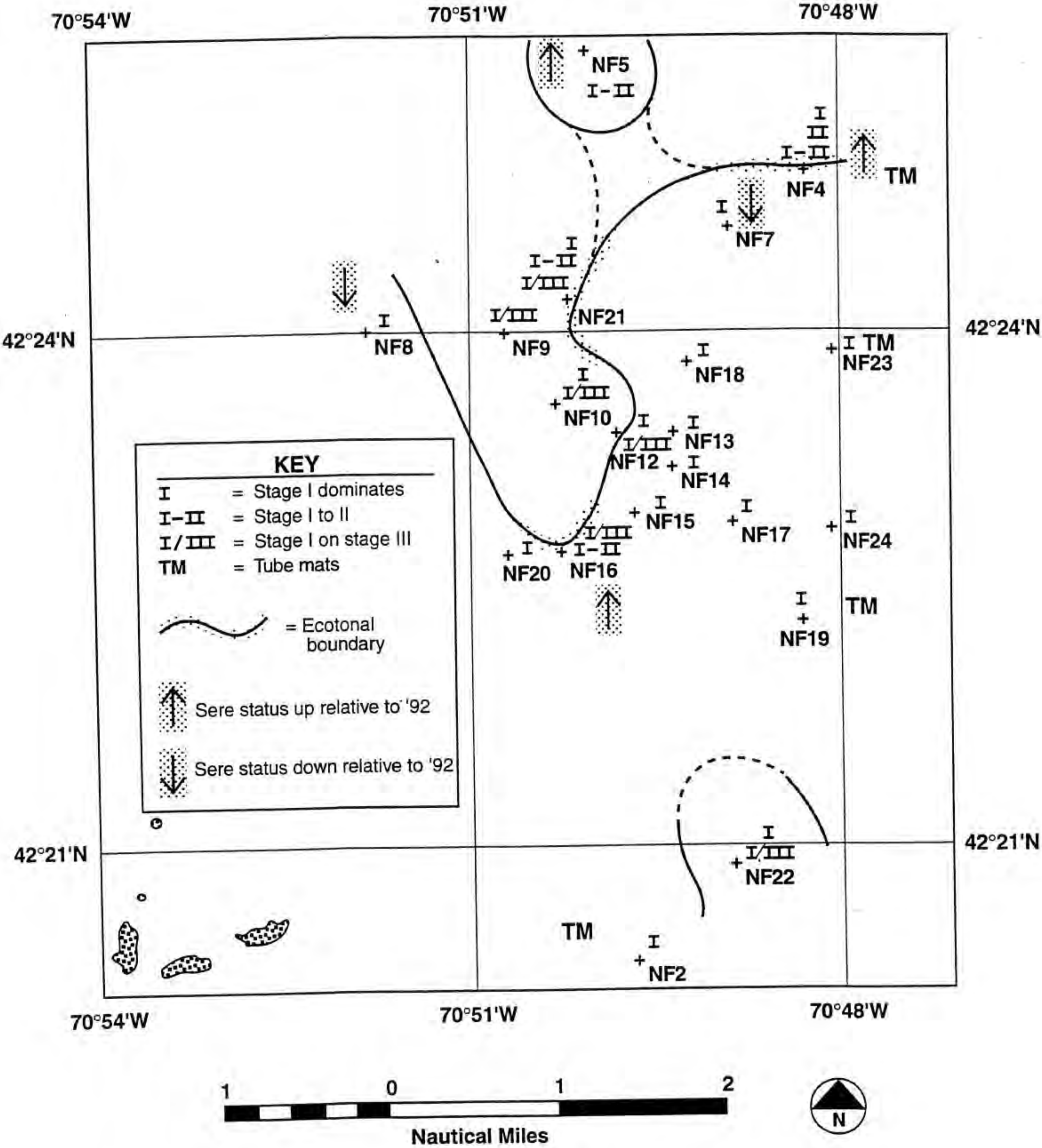
1995 Distribution of Major Modal Grain Size and Other Sedimentary Features in the Nearfield. Data are from Sediment Profile Images (SPI).

fig 7



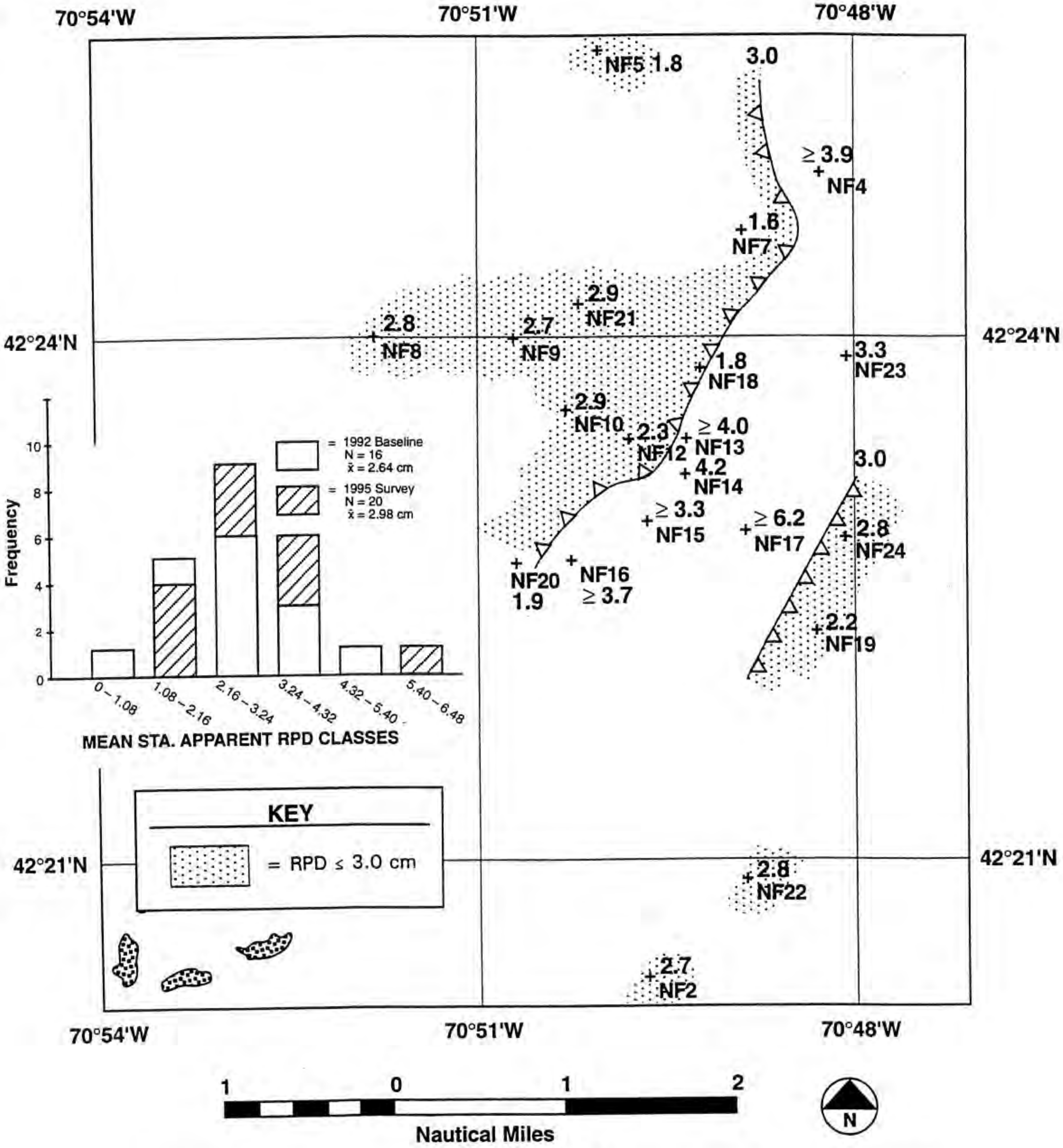
1995 Distribution of Average Total Organic Carbon Contents (wt%) in the Nearfield. Note that the contour intervals are unequal.

fig 8



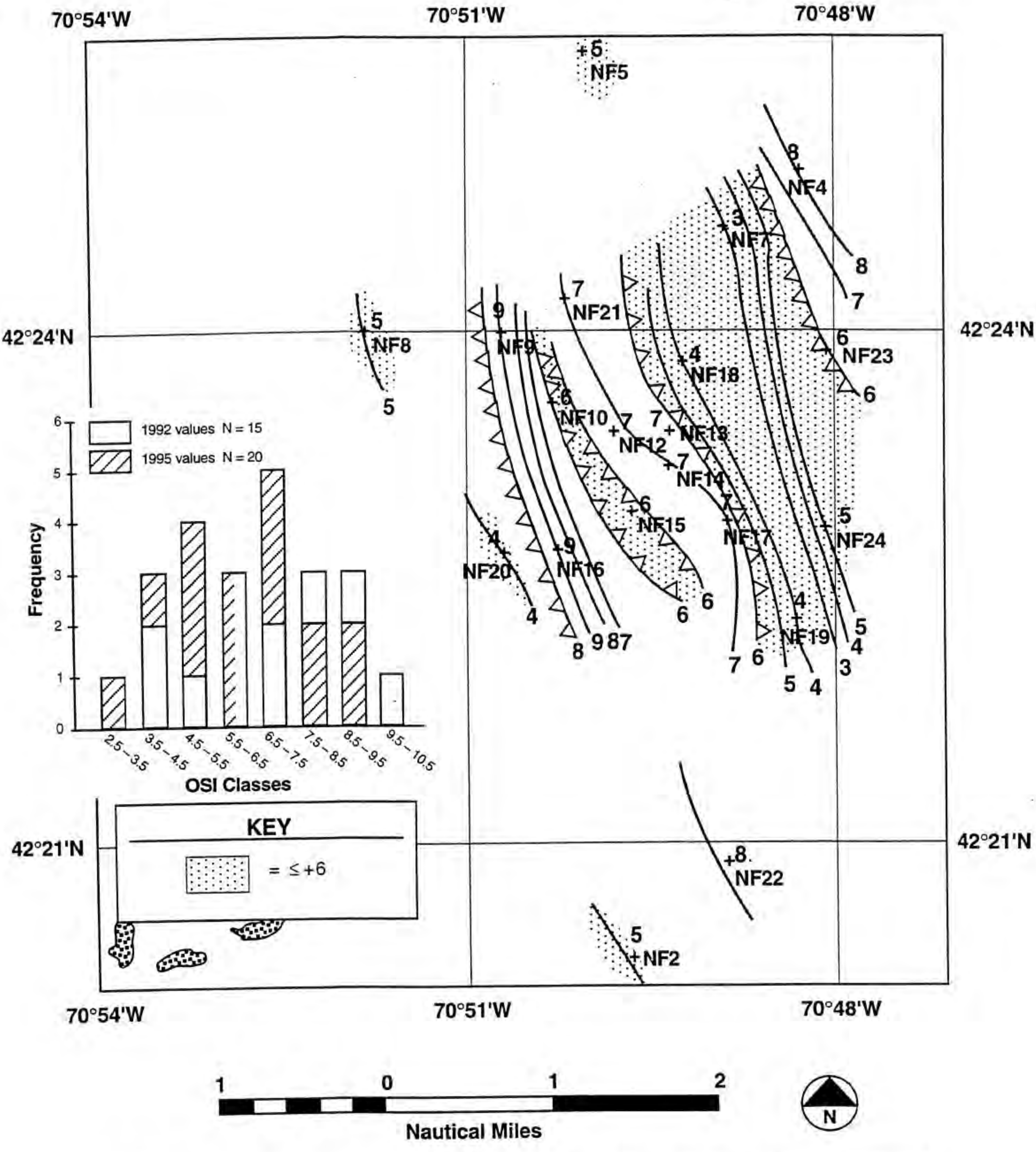
1995 Distribution of Successional Stages in the Nearfield.

fig 9



1995 Distribution of Mean Apparent Redox Potential Discontinuity (RPD) Depths in the Nearfield (cm below Sediment-Water Interface). Contours delimit areas of RPD ≤ 3.0 cm depth. Inset shows RPD depth frequency distributions for 1992 and 1995.

fig 10

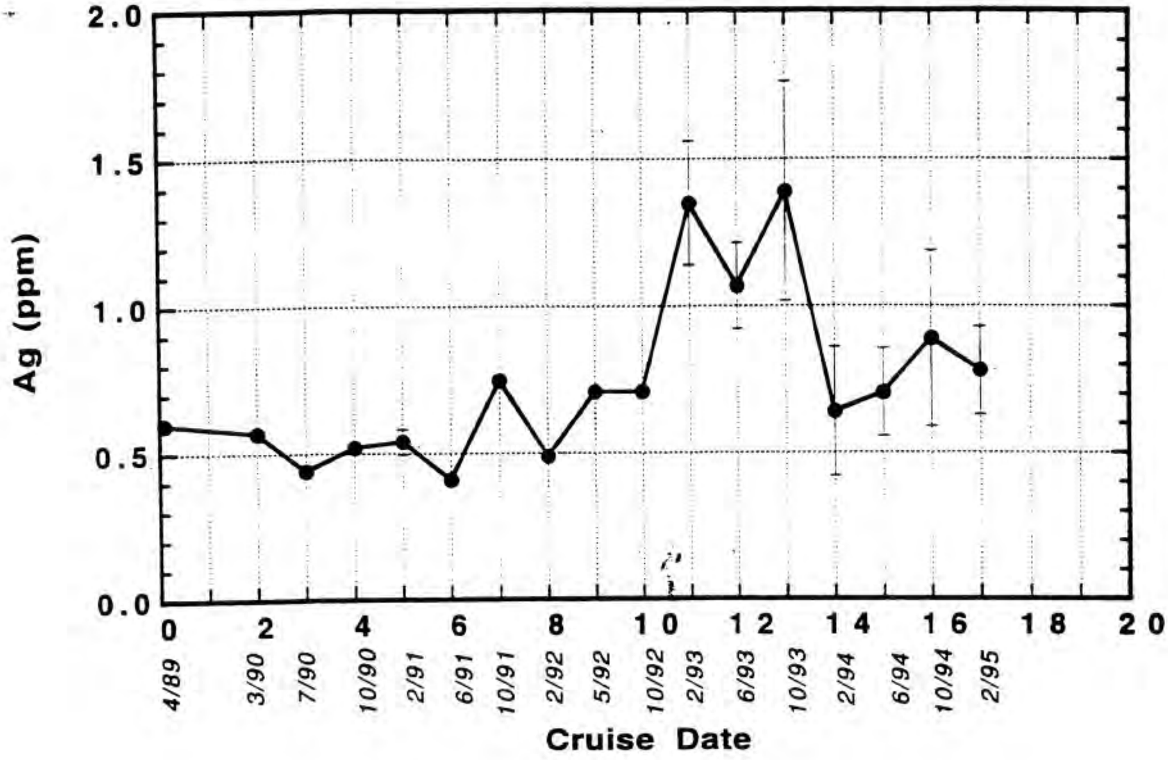


1995 Distribution of Organism-Sediment Indices (OSIs) in the Nearfield Contoured on 3 through 9 OSI Isopleths. Inset shows OSI frequency distributions for 1992 and 1995.

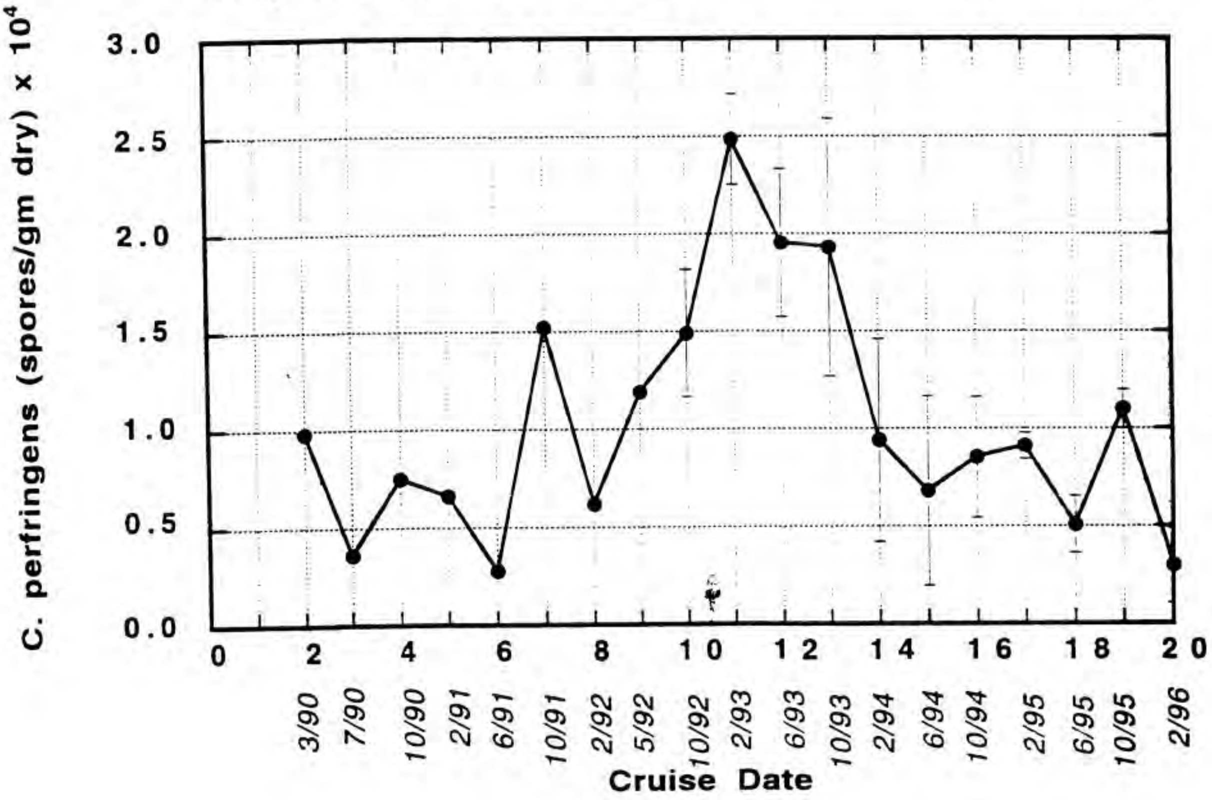
APPENDIX C-3

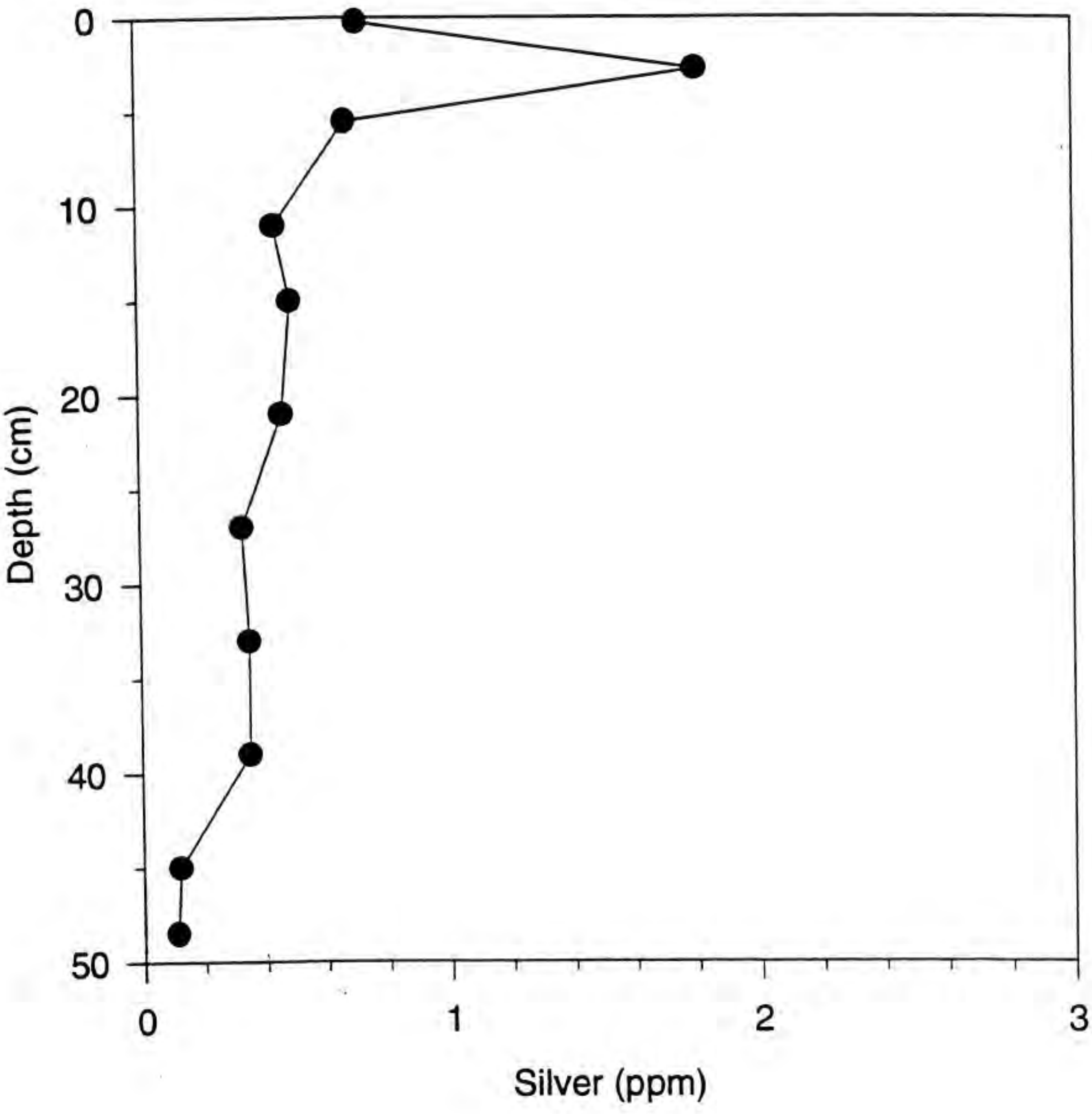
Mike Bothner
USGS

Silver vs. Time **Station 3**

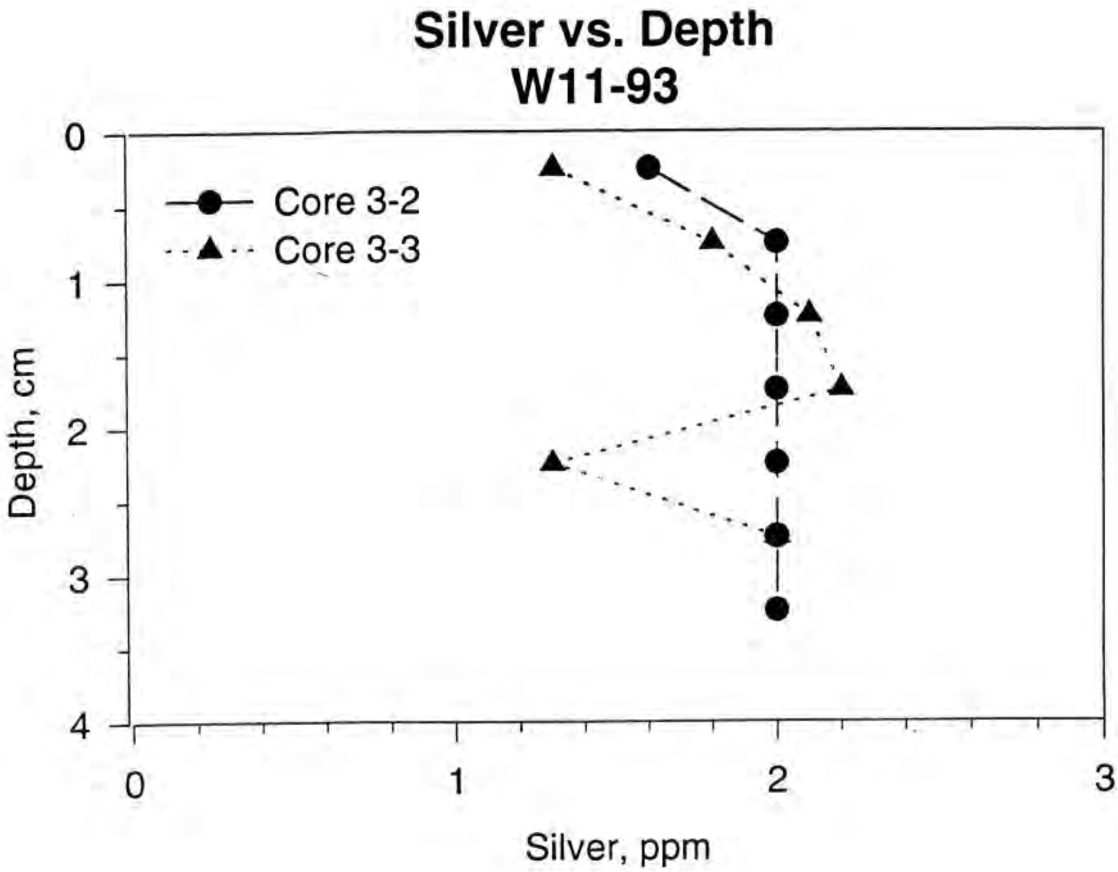


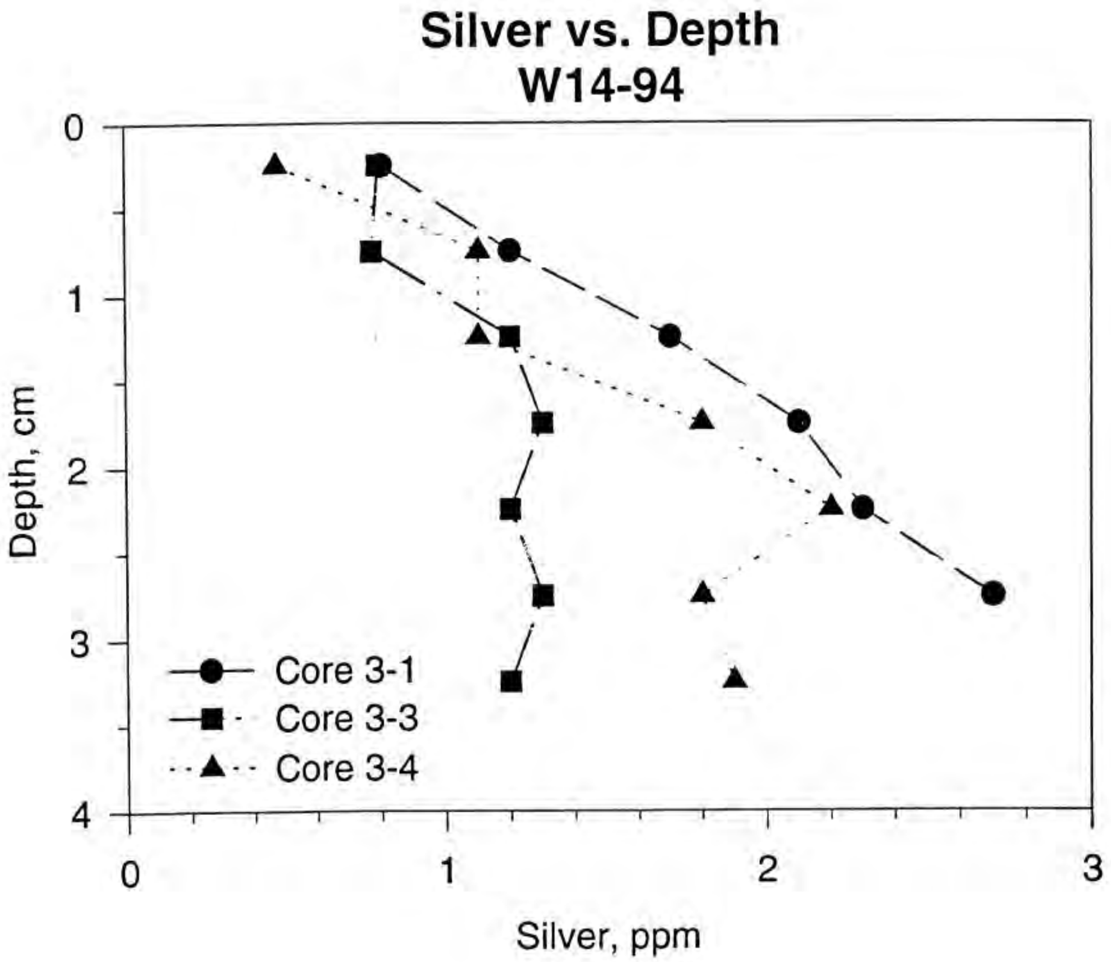
C. perfringens vs. Time **Station 3**





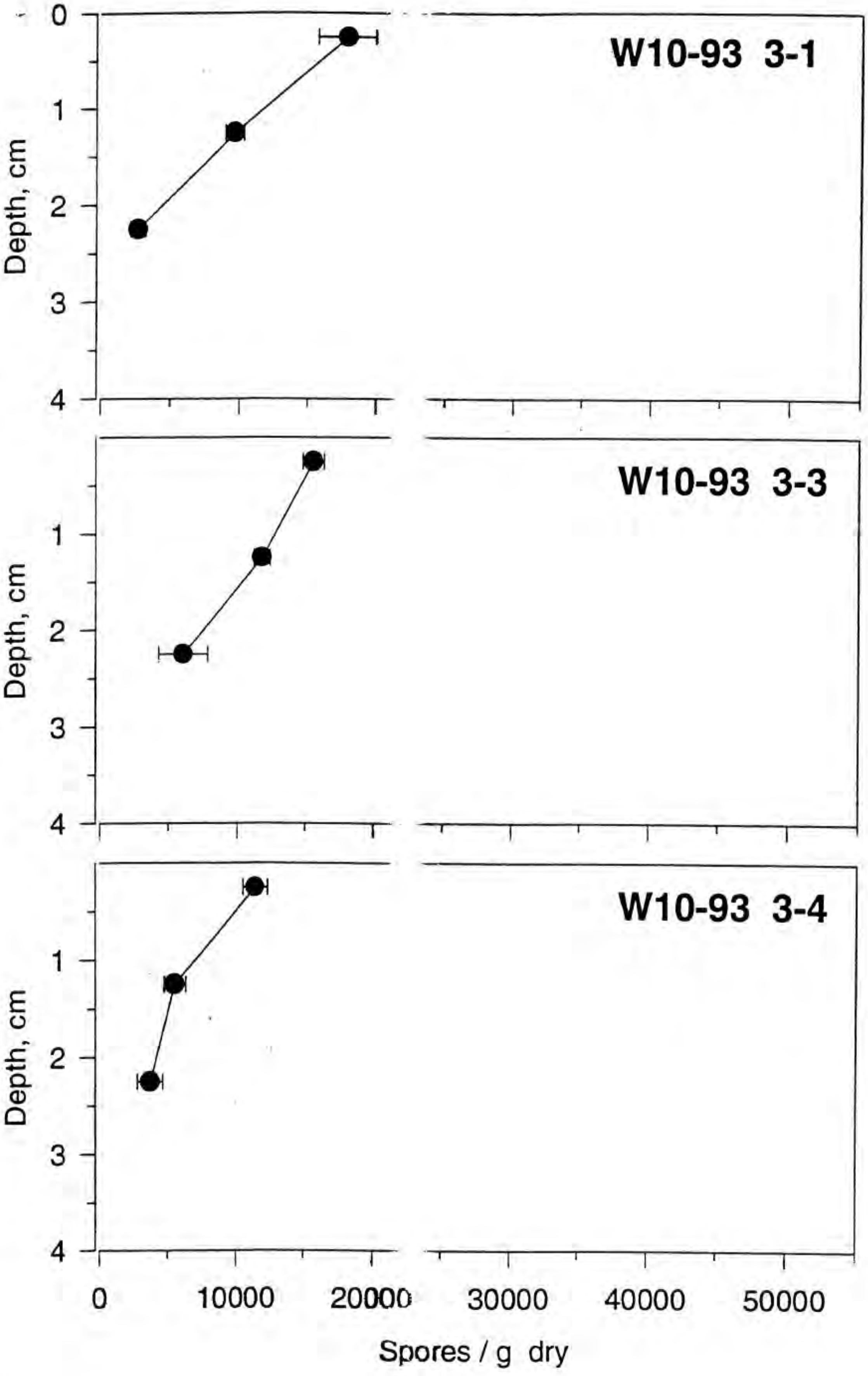
Silver vs. Depth
AM2-92 WH3-S3


Silver vs. Depth
W11-93
Core 3-2
Core 3-3
Depth, cm
0
1
2
3
4
0
1
2
3
Silver, ppm


Silver vs. Depth
W14-94
Core 3-1
Core 3-3
Core 3-4
Depth, cm
0
1
2
3
4
0
1
2
3
Silver, ppm

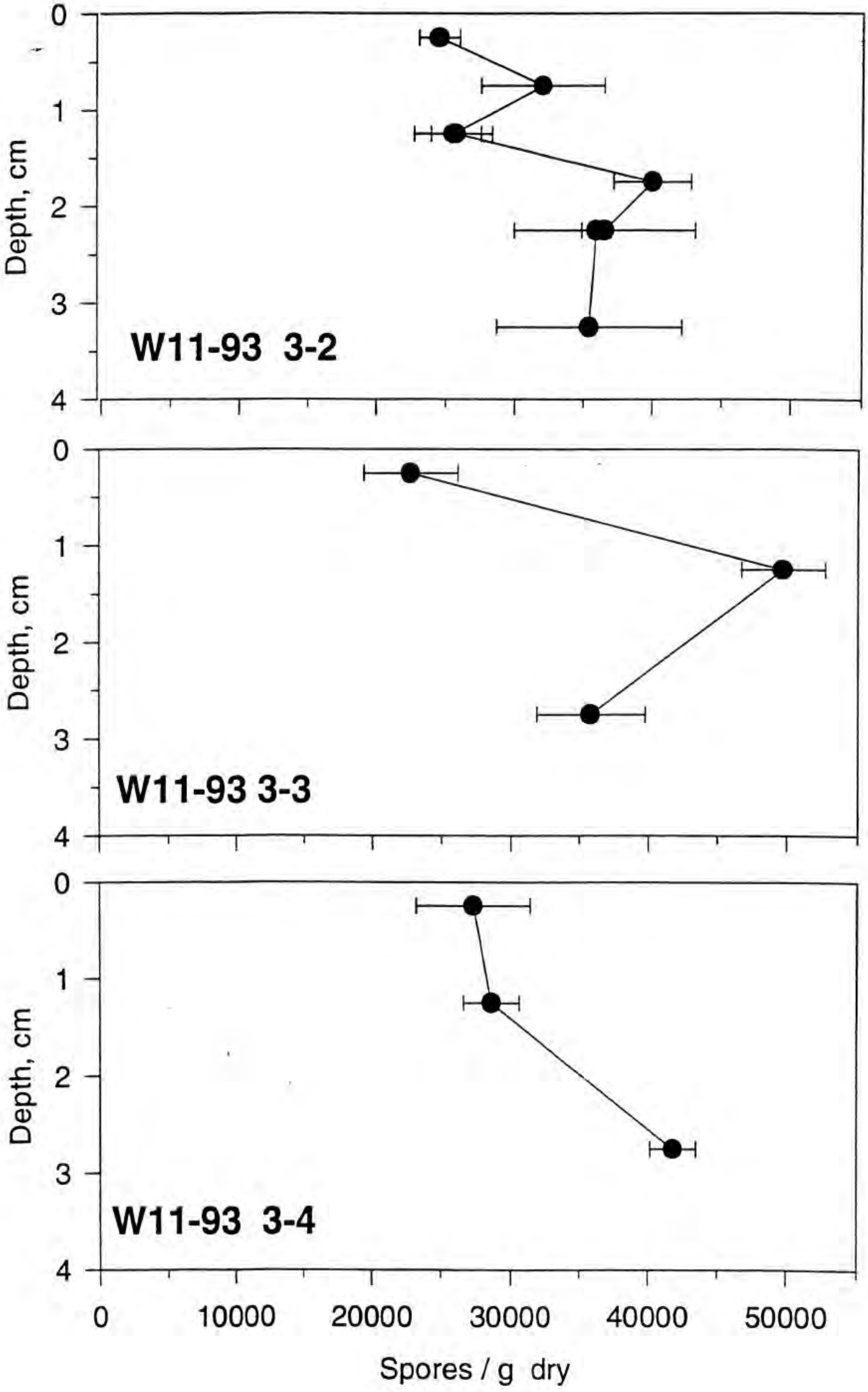
PRE STORM

Clostridium perfringens vs. Depth



POST STORM

Clostridium perfringens vs. Depth

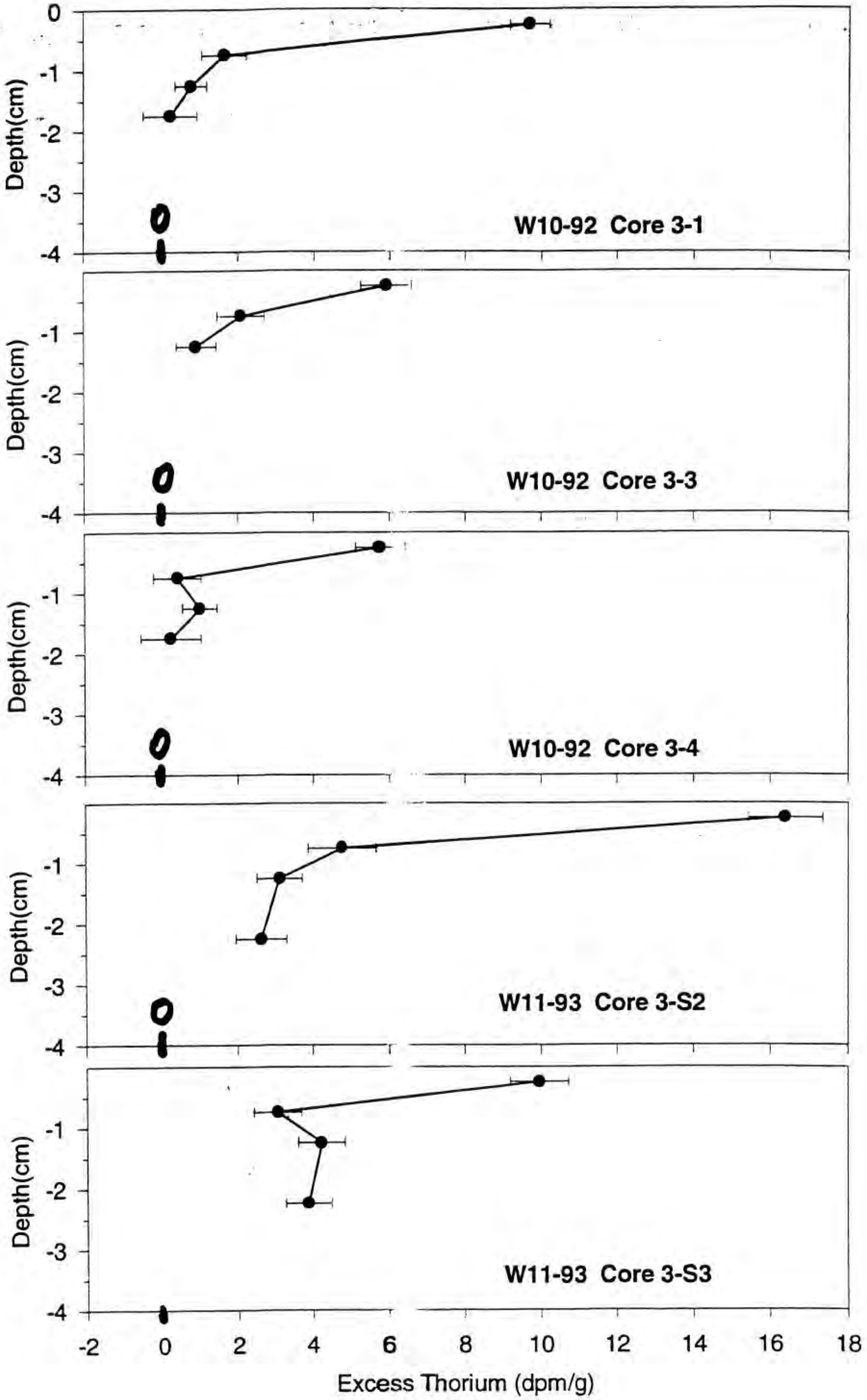


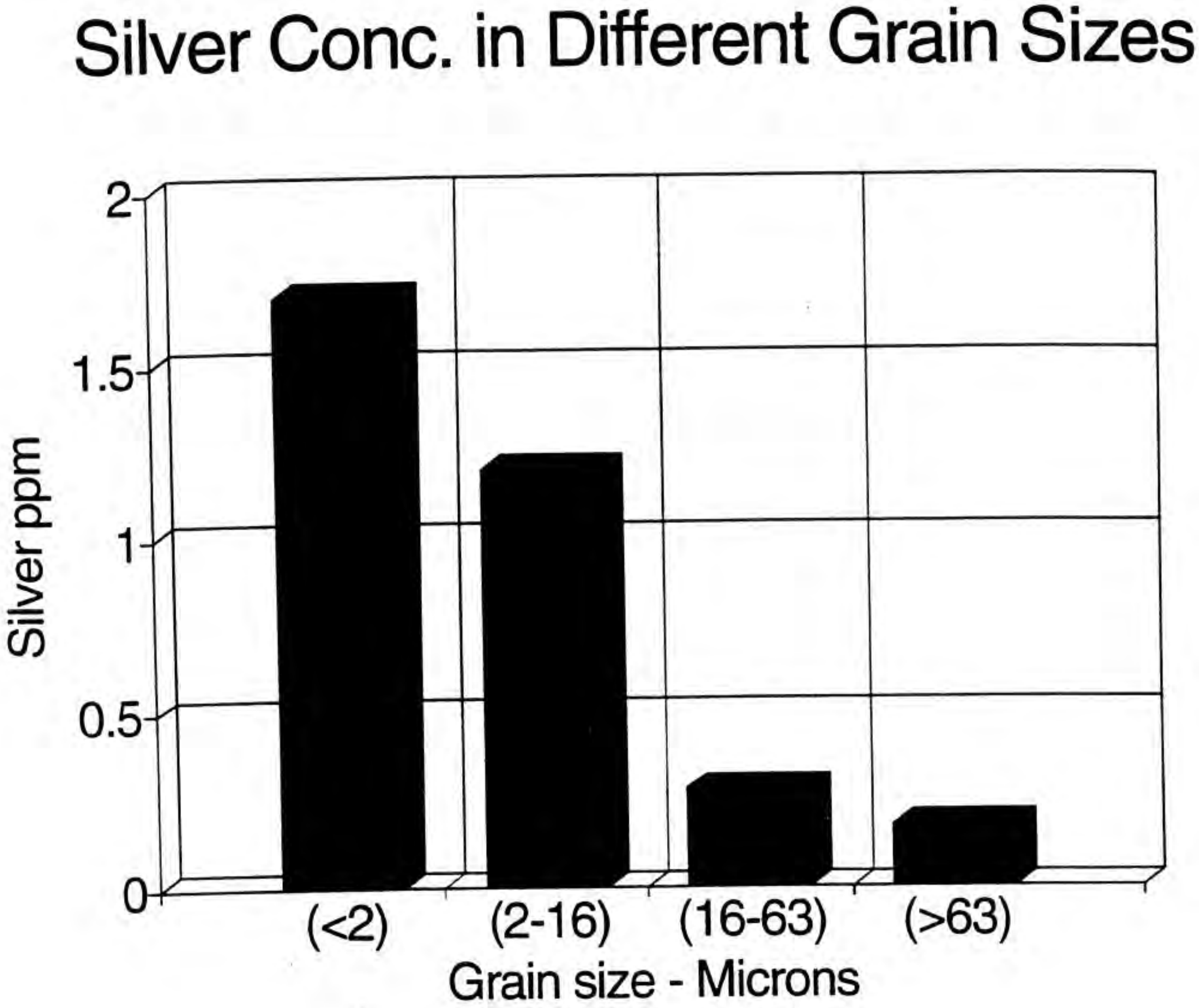
6

Excess Thorium 234

PRE STORM

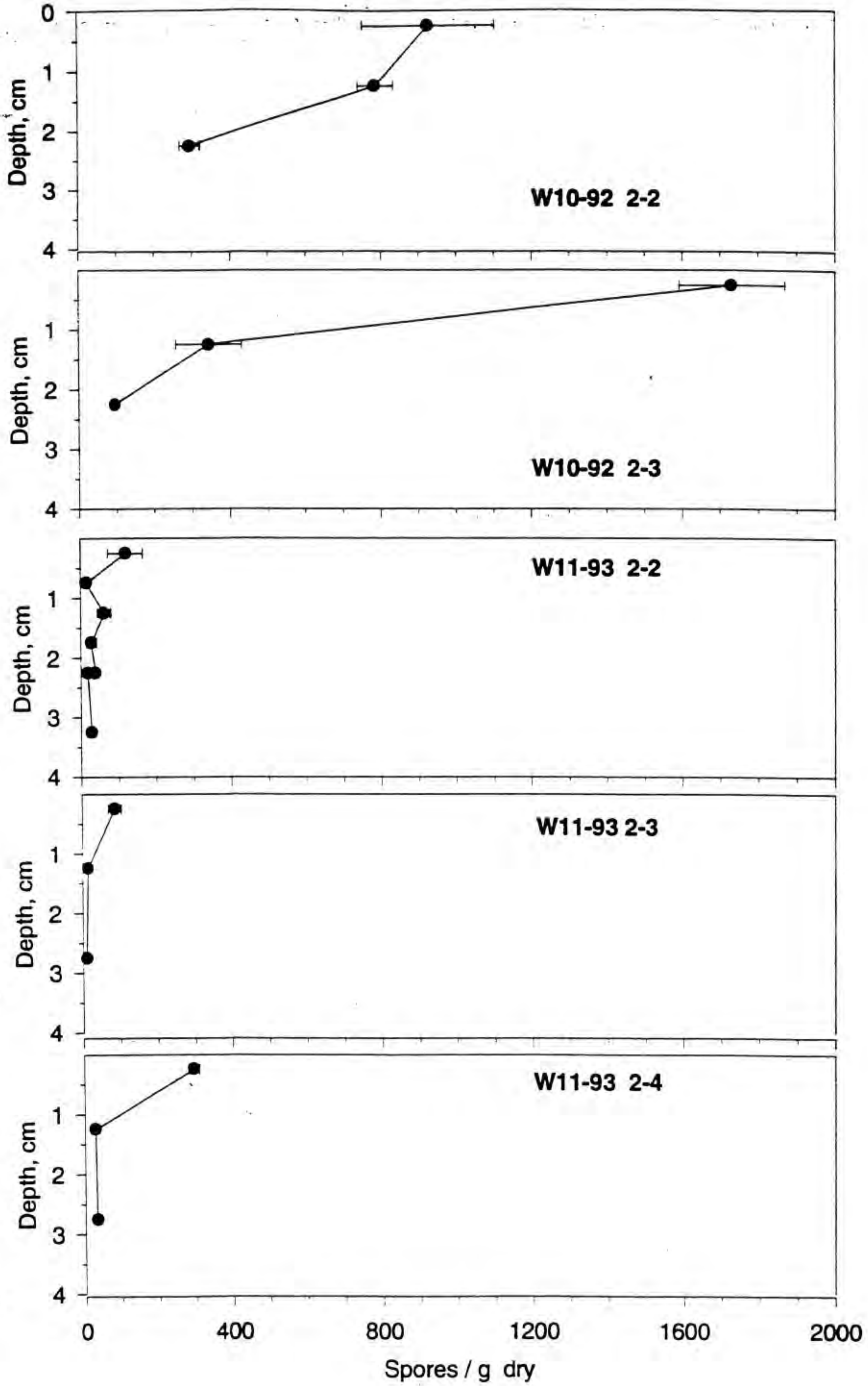
POST STORM




Silver Conc. in Different Grain Sizes
Silver ppm
2
1.5
1
0.5
0
(<2)
(2-16)
(16-63)
(>63)
Grain size - Microns

8

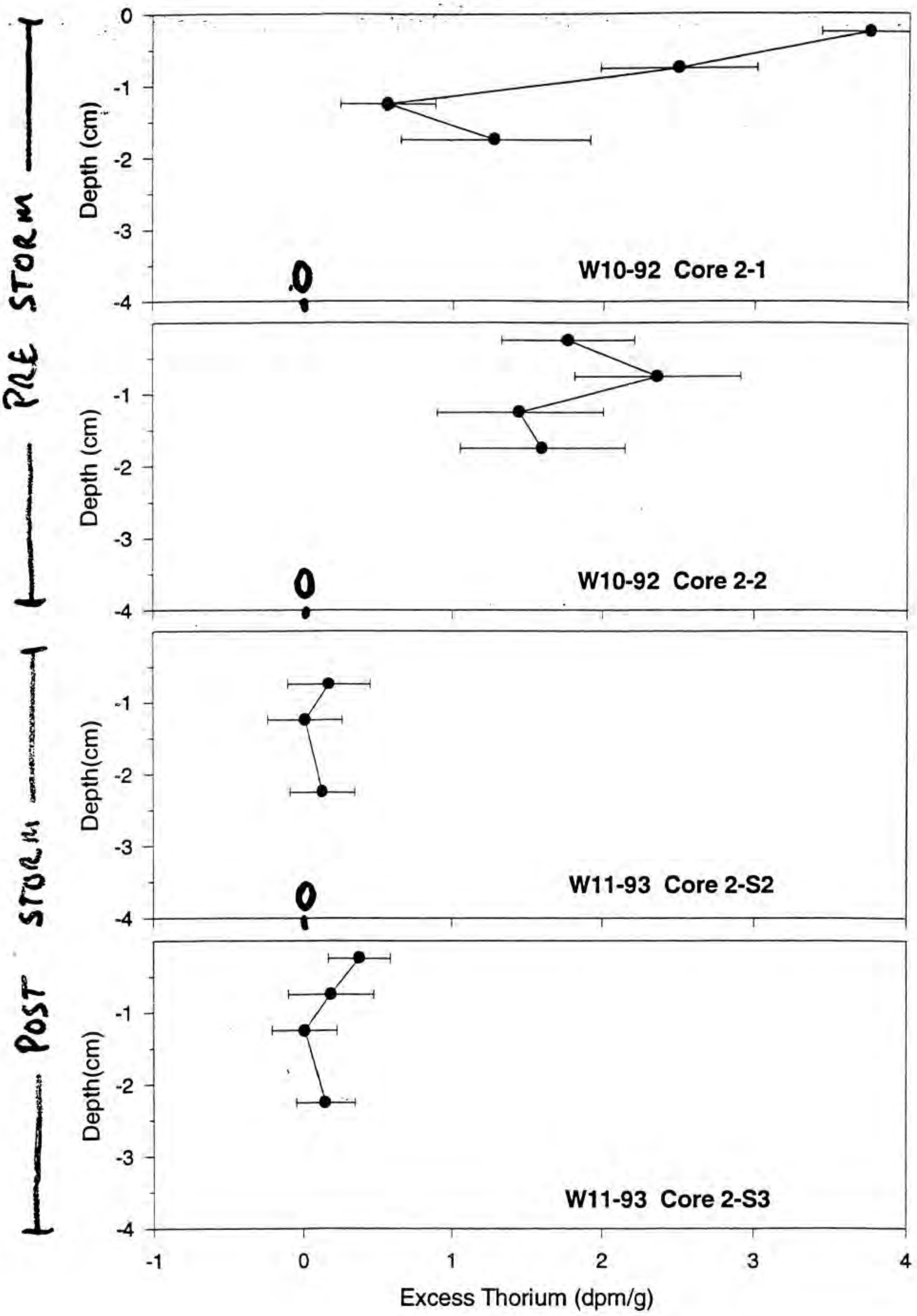
Clostridium perfringens vs. Depth

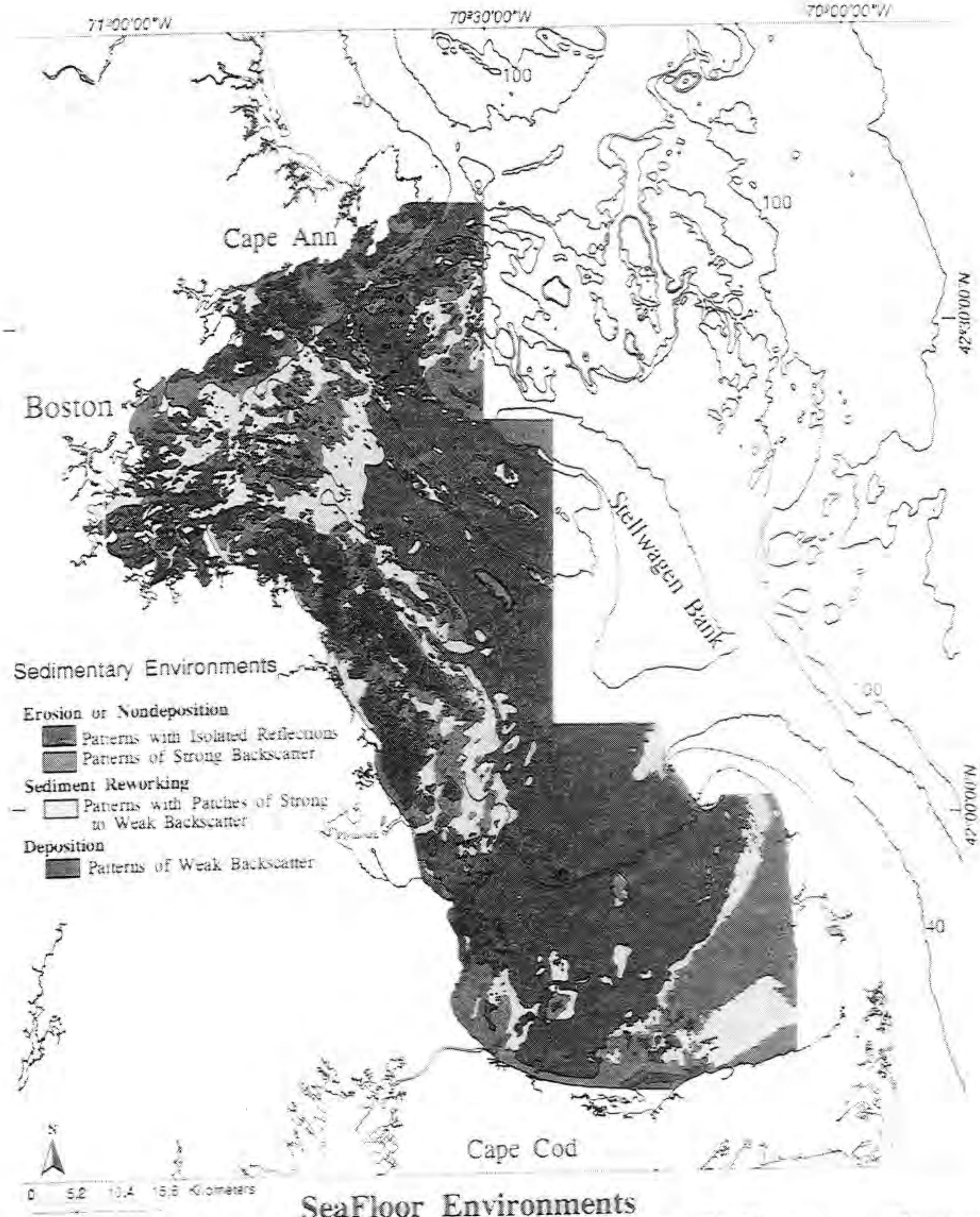


|— PRE STORM —|

|— POST STORM —|

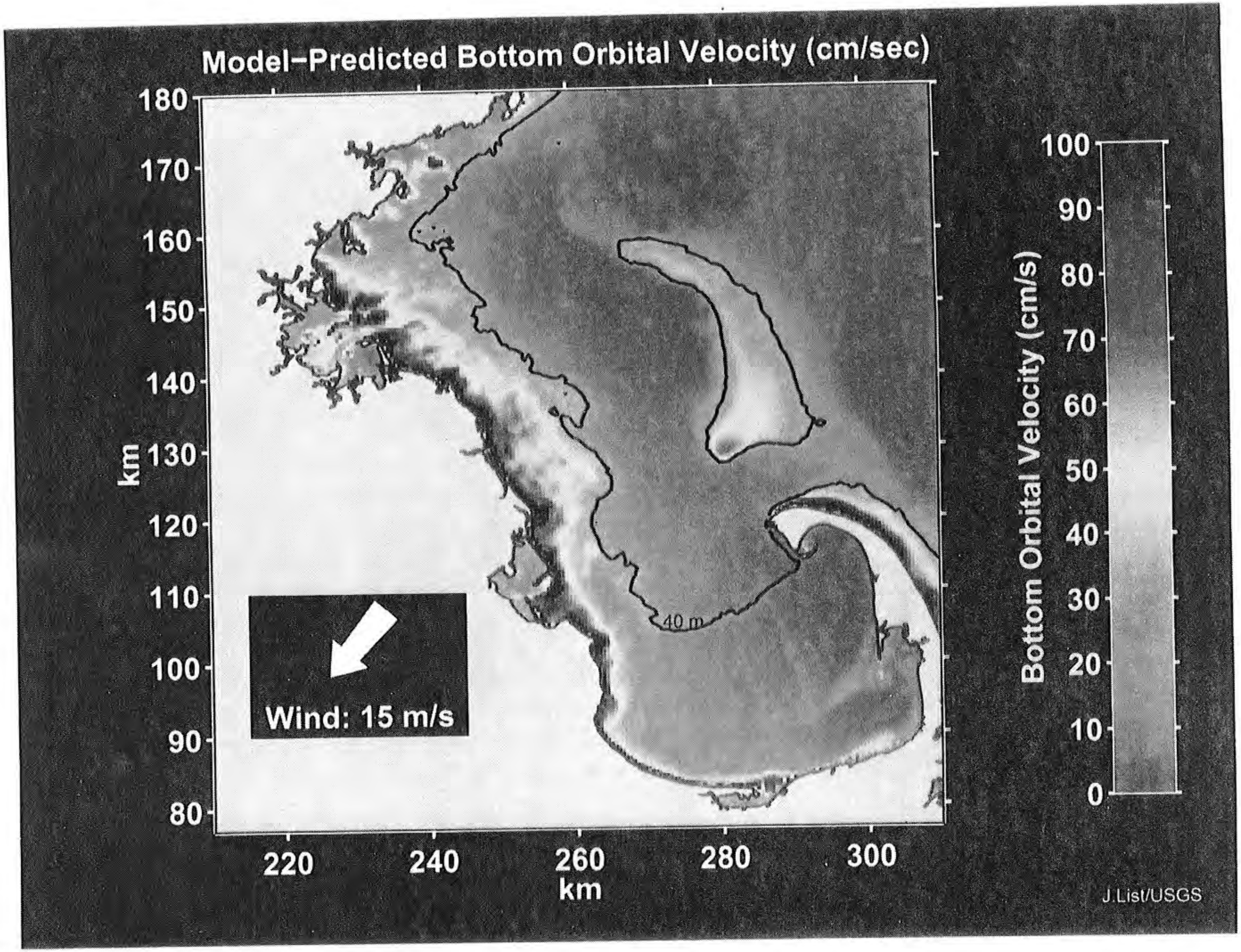
Excess Thorium





SeaFloor Environments
Within the Boston Harbor - Massachusetts Bay Sedimentary System

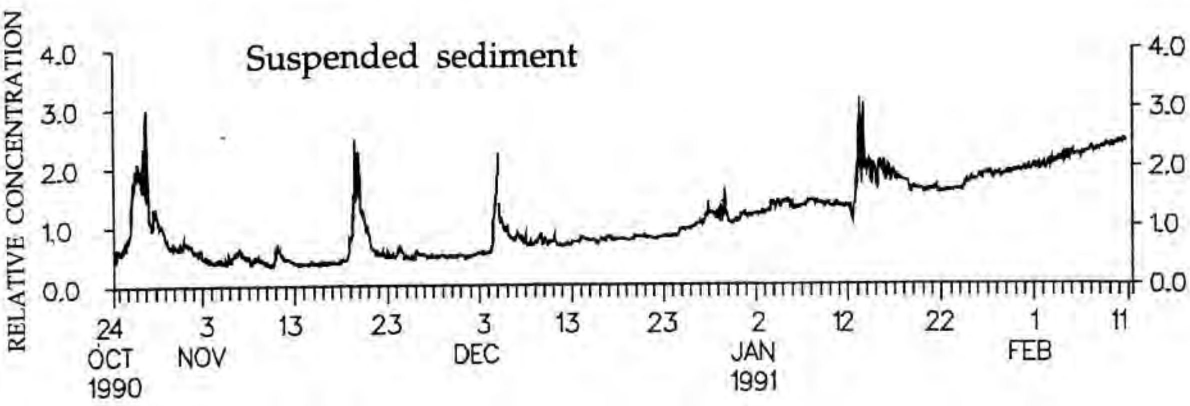
U.S. Geological Survey

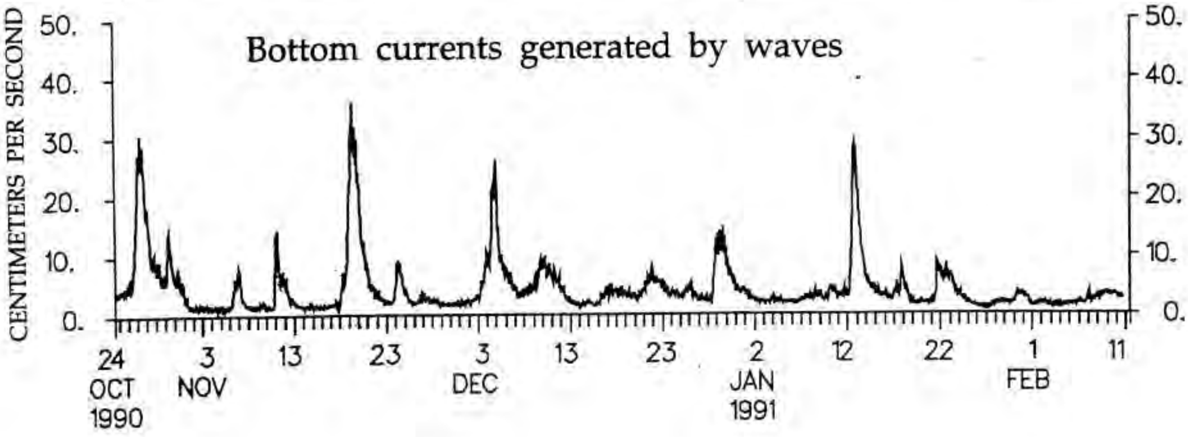


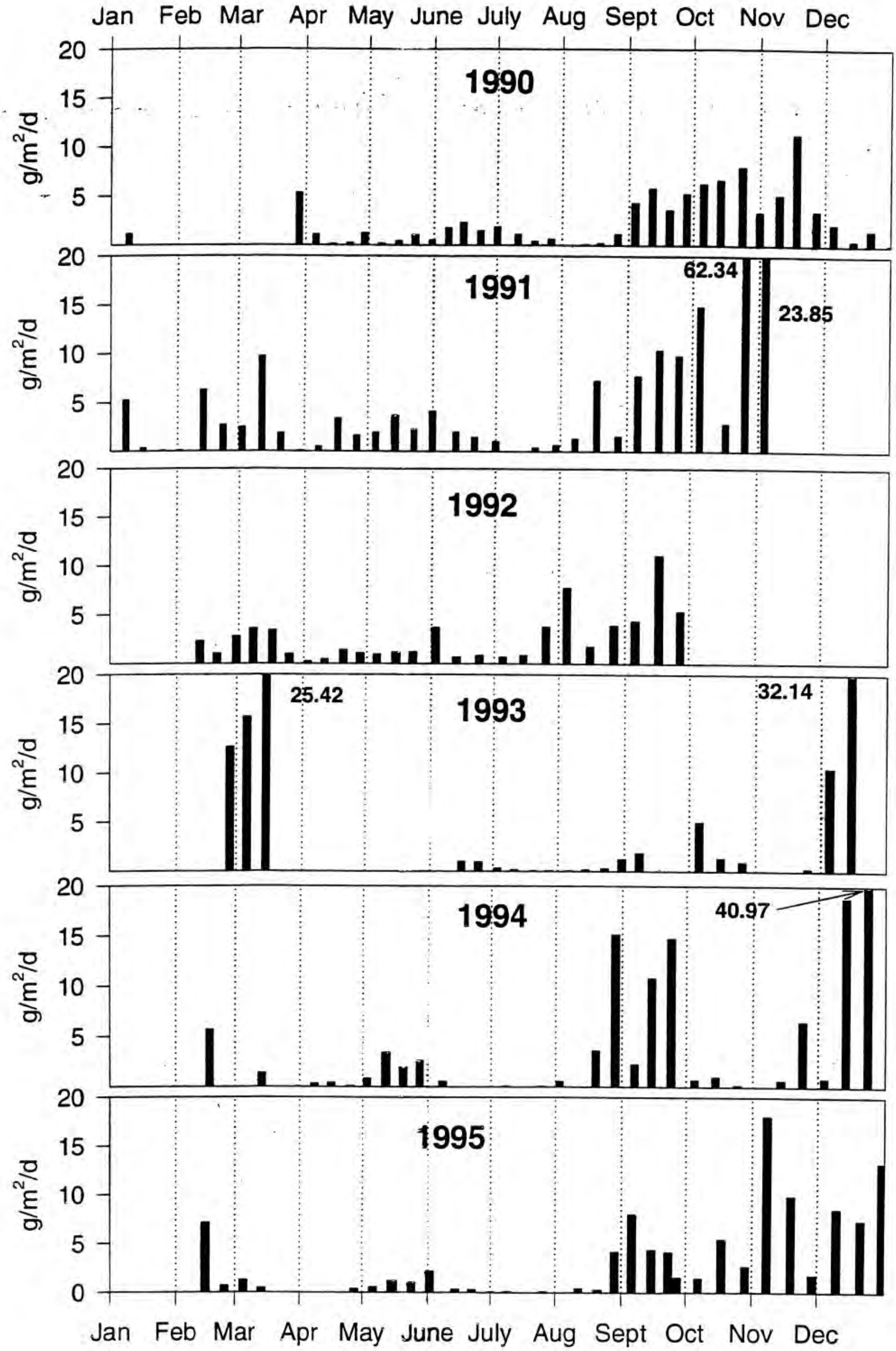
Model–Predicted Bottom Orbital Velocity (cm/sec)

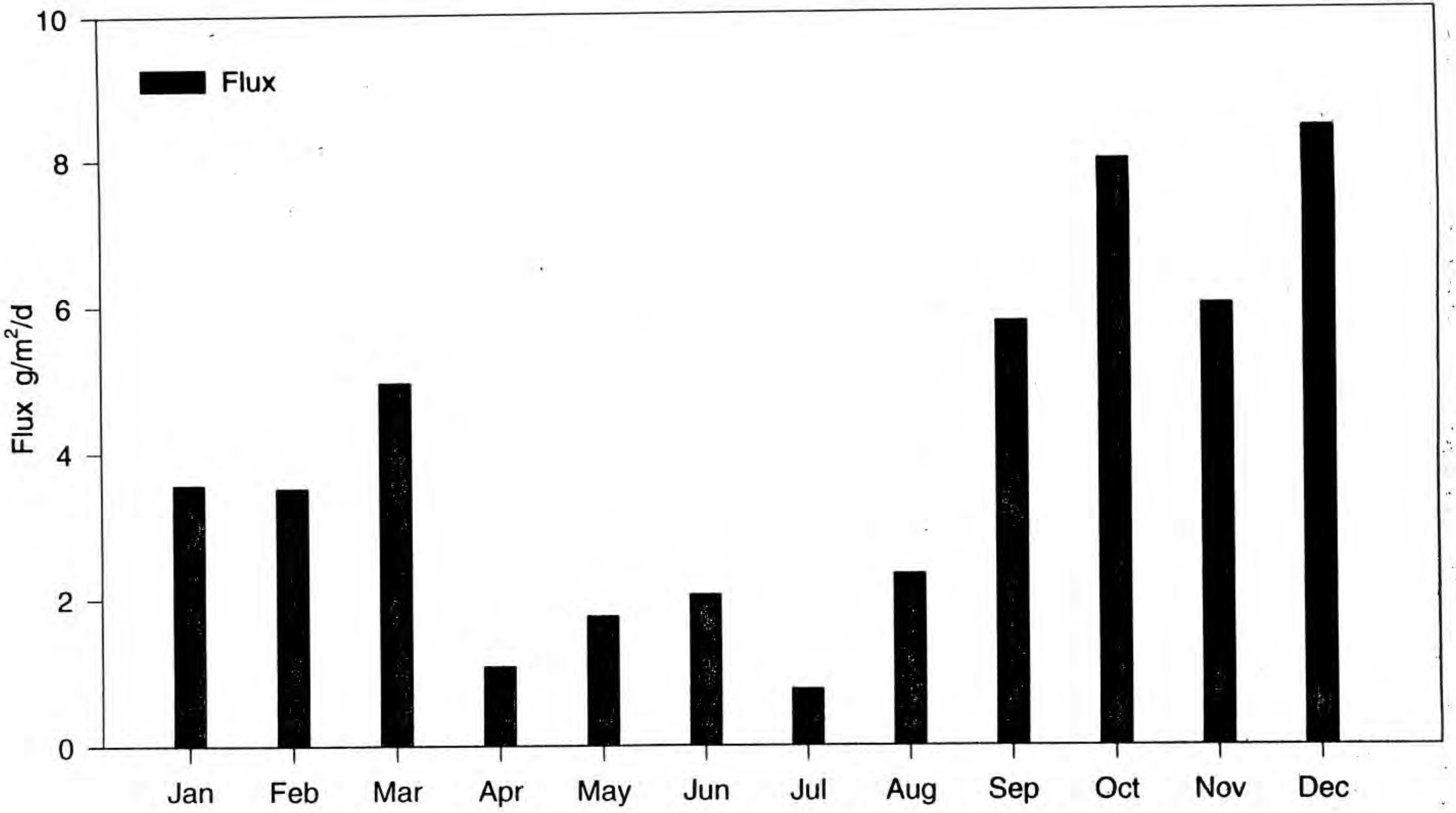
J.List/USGS

Sediment Trap Bottles


Suspended sediment

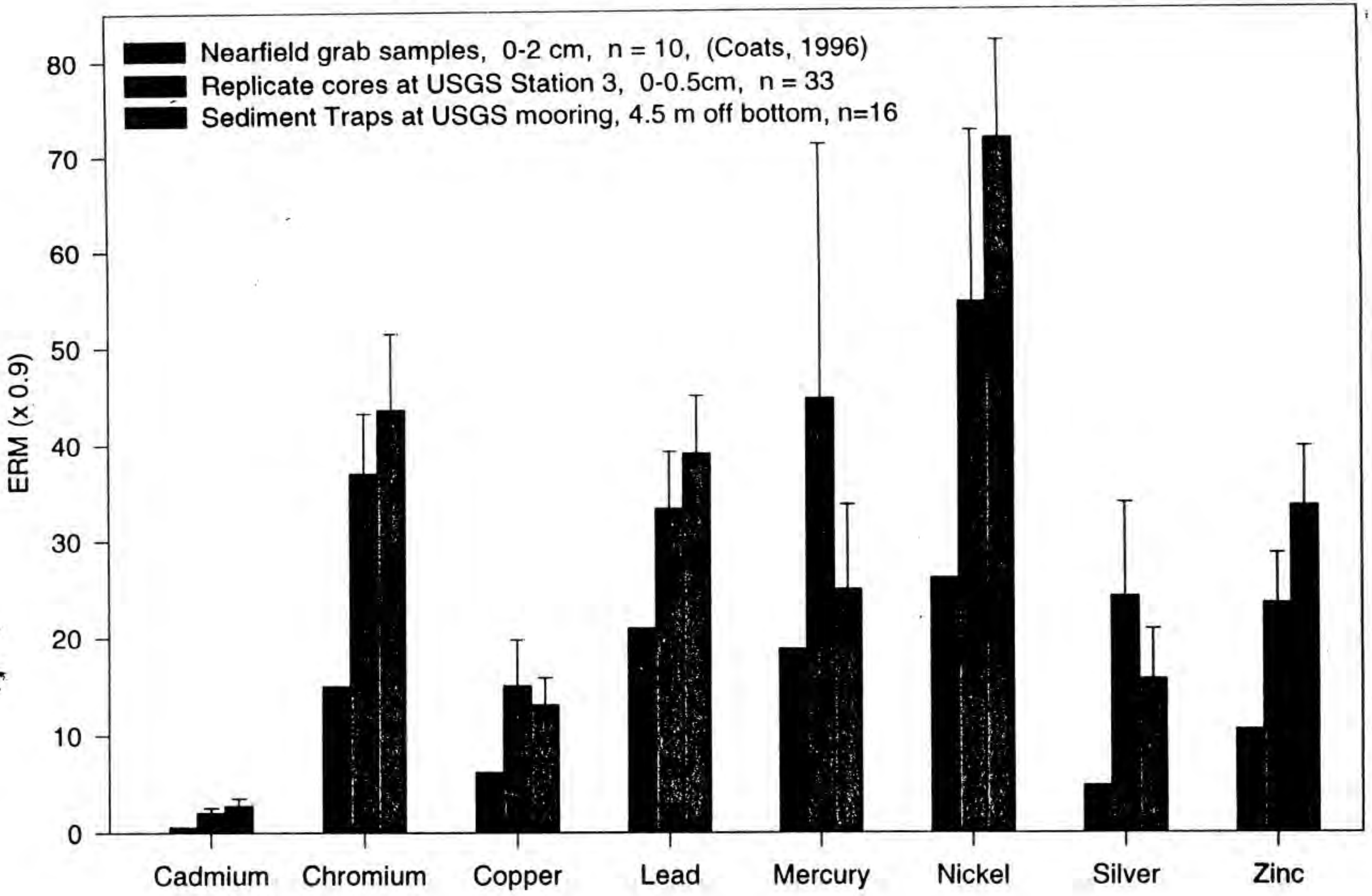

Bottom currents generated by waves


Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
1990
1991
62.34
23.85
1992
1993
25.42
32.14
1994
40.97
1995
g/m^2/d
0
5
10
15
20



Average Monthly Trap Flux
1990-1995

Average Metal Concentration in Bottom and Suspended Sediments Near Future Outfall as Percent of ERM (x 0.9)



APPENDIX C-4

Gordon Wallace
UMASS Boston

SEDIMENT CHEMISTRY
METALS

GORDON T. WALLACE
Environmental, Coastal, and Ocean Sciences Program
University of Massachusetts at Boston
and
Envitec, Inc.

RAVEENDRA V. IKA
Envitec Inc.

JAMES P. SHINE
Department of Environmental Health
Harvard School of Public Health

HYPOTHESES

- Sediment contaminant concentrations at mid-field (2-7 km from outfall) stations will not exceed 90% of NOAA ER-M Values.
- Sediment contaminant concentrations at mid-field stations will not exceed 90% of available EPA sediment criteria.

SAMPLING DESIGN

- Surface grab samples
- "Near-" and Far-" Field samples
- Analytes

  Metals (Cu, Zn, Pb, Cd, Hg, Ag, Ni, Cr, Fe and Al)

  Organic Carbon

  Grain Size

- Analysis

  <u>1992 - 1994</u>

  Energy Dispersive X-Ray Fluorescence (EDXRF)
  (Cu, Zn, Pb, Ni, Cr, Fe, Al)

  Graphite Furnace Atomic Absorbtion Spectrophotometry
  (GFAAS) - (Ag, Cd)

  Cold-Vapor Atomic Absorption Spectrometry (CVAAS) - (Hg)

  <u>1995</u>

  Inductively Coupled Plasma - Mass Spectrometry (ICP-MS)
  (all metals)

CONTROLLING VARIABLES

- **SOLID PHASE**

  MnO_x

  FeO_x

  Organic Matter (OM)

- **AQUEOUS PHASE**

  Free Metal Ion Activities {M}

  Free Ligand Activities {L}

  Ancillary Variables (pH, Eh, solution composition, P, T)

EQUILIBRIUM CONSIDERATIONS

- **AQUEOUS PHASE**

$$M + L_i \leftrightarrows ML_i$$

$$K_{L_i}^{*} = \frac{[ML_i]}{[M]\ [L_i]}$$

$$[ML_i] = K_{L_i}^{*}\ [M]\ [L]$$

- **SOLID PHASE**

$$[M] + [S_i] \leftrightarrows [MS_i]$$

$$K_{S_i}^{*} = \frac{[MS_i]}{[M]\ [S_i]}$$

$$[MS_i] = K_{S_i}^{*}\ [M]\ [S_i]$$

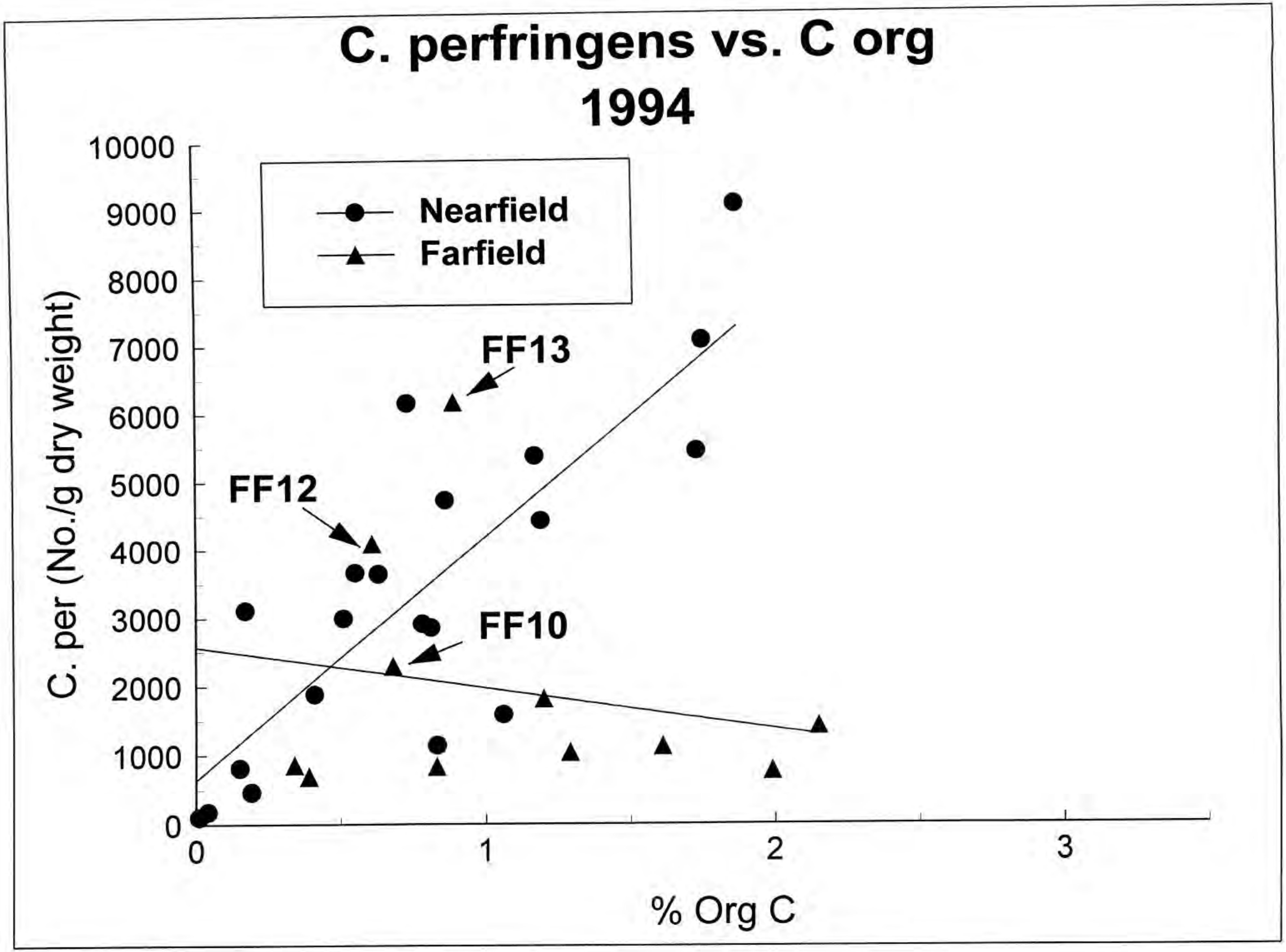
$$[M_T] = [M]\ (1 + \Sigma K^*_{L_i}\ [L_i] + \Sigma K^*_{S_i}\ [S_i])$$

ASSUMING:

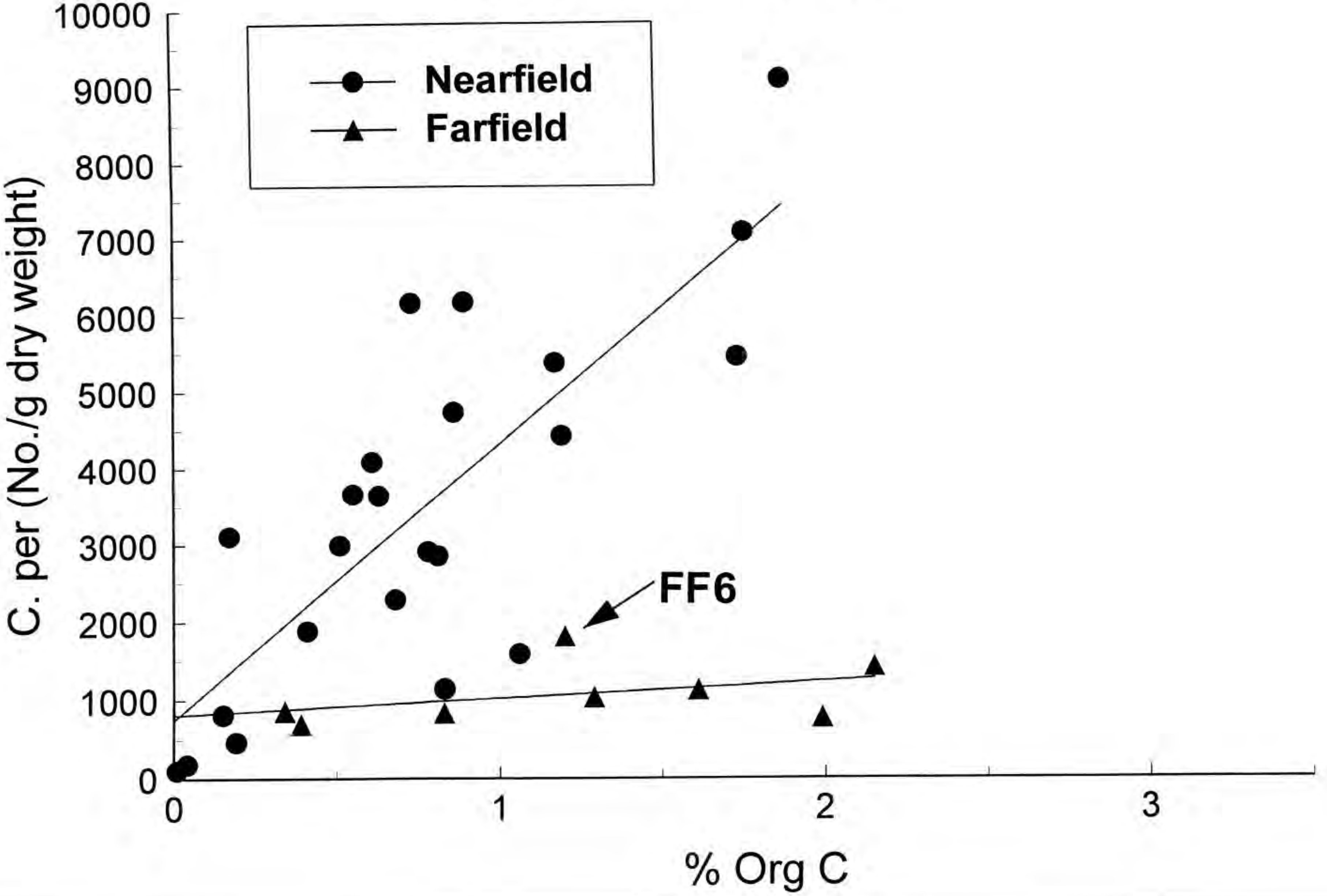
- $[M]_{\text{Sediment pore waters}} = [M]_{\text{Water Column}}$
- $[L_i]_{\text{Sediment pore waters}} = [L_i]_{\text{Water Column}}$
- $[S_i]$ is dominated by the contribution of organic matter and is $\propto$ to the organic matter content $[C_{org}]$ of the sediments.

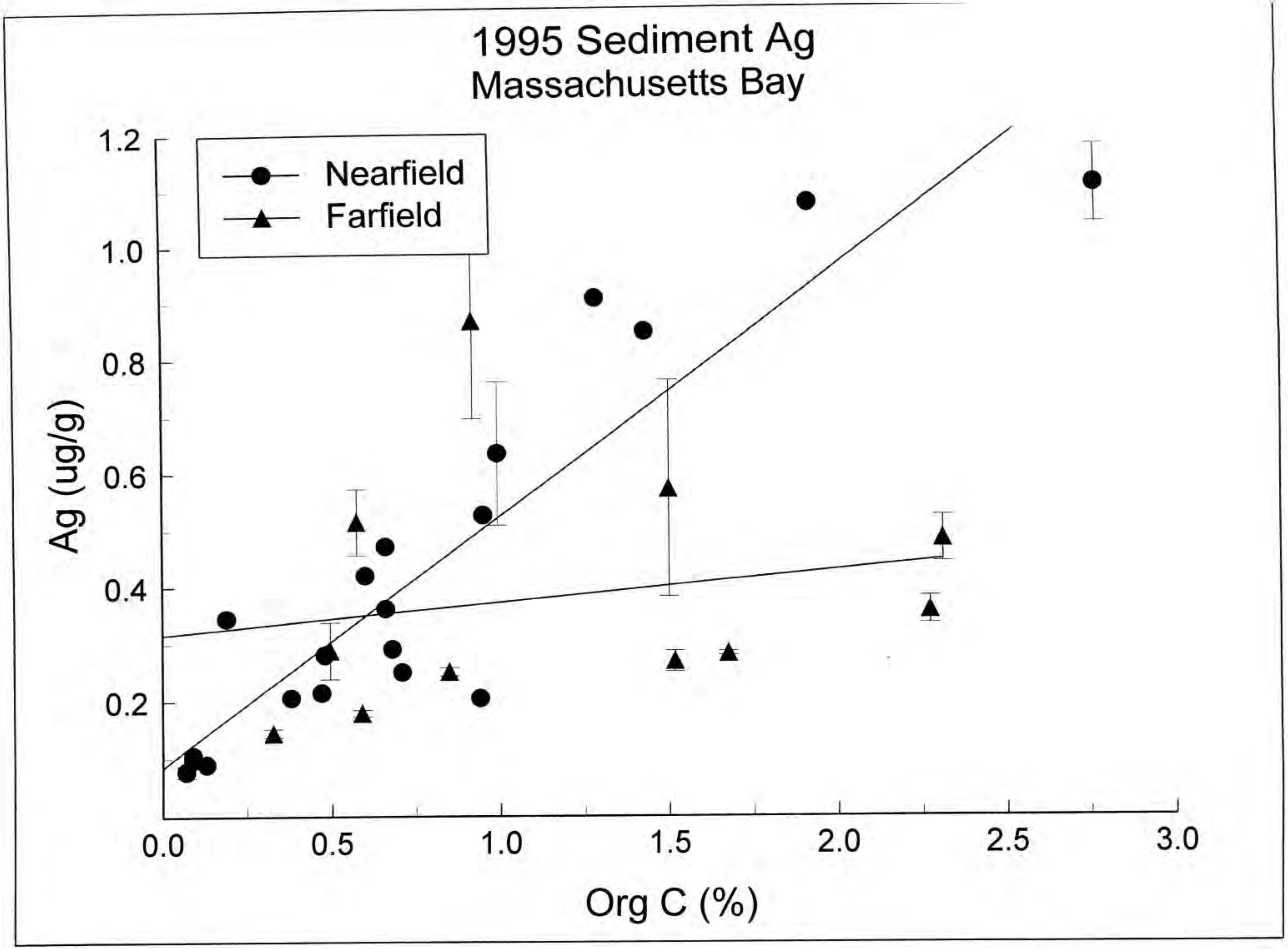
THEN:

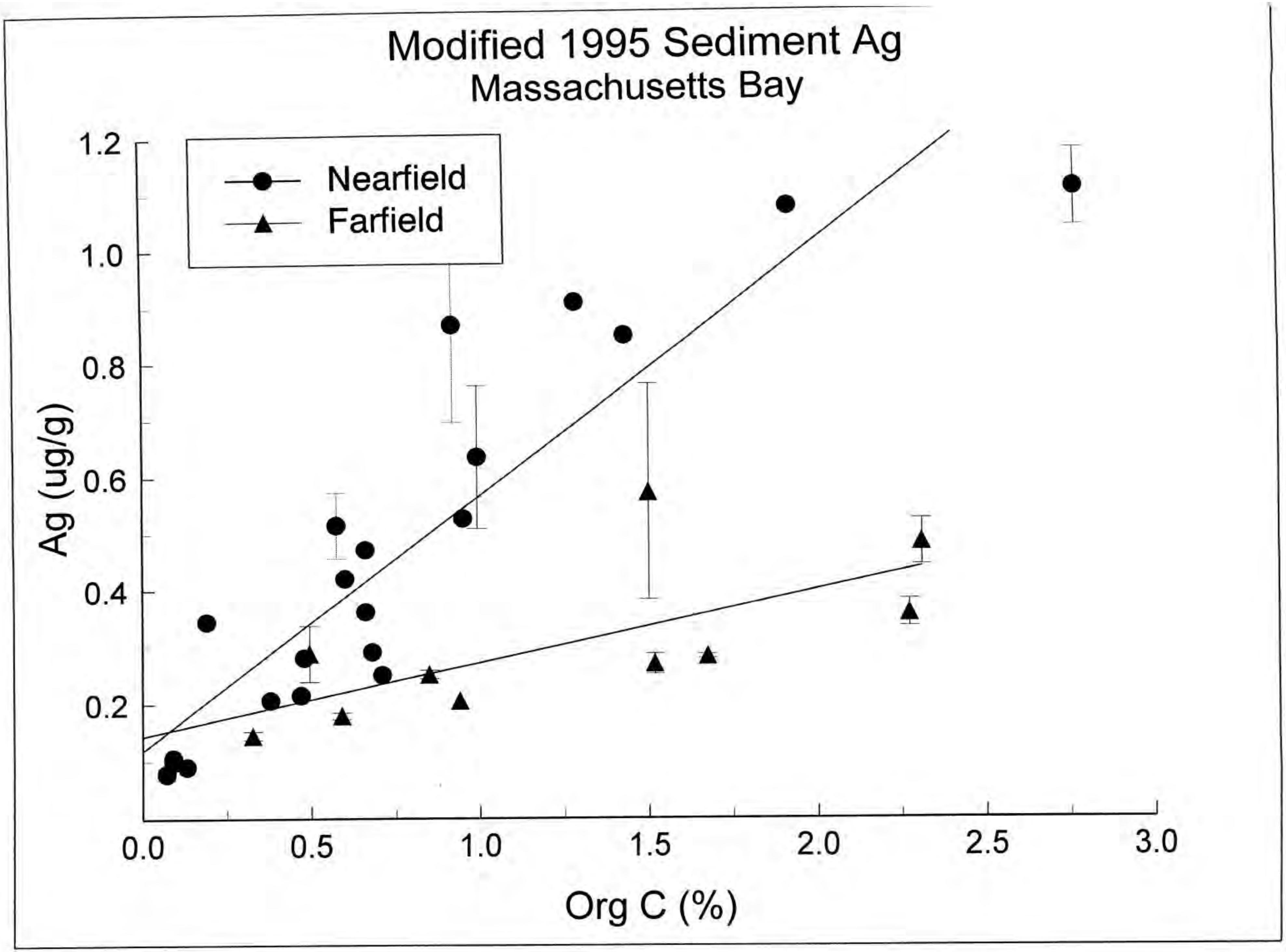
$$[M_{Sed}] = K^*_{C_{org}}\ [M]\ [C_{org}]$$

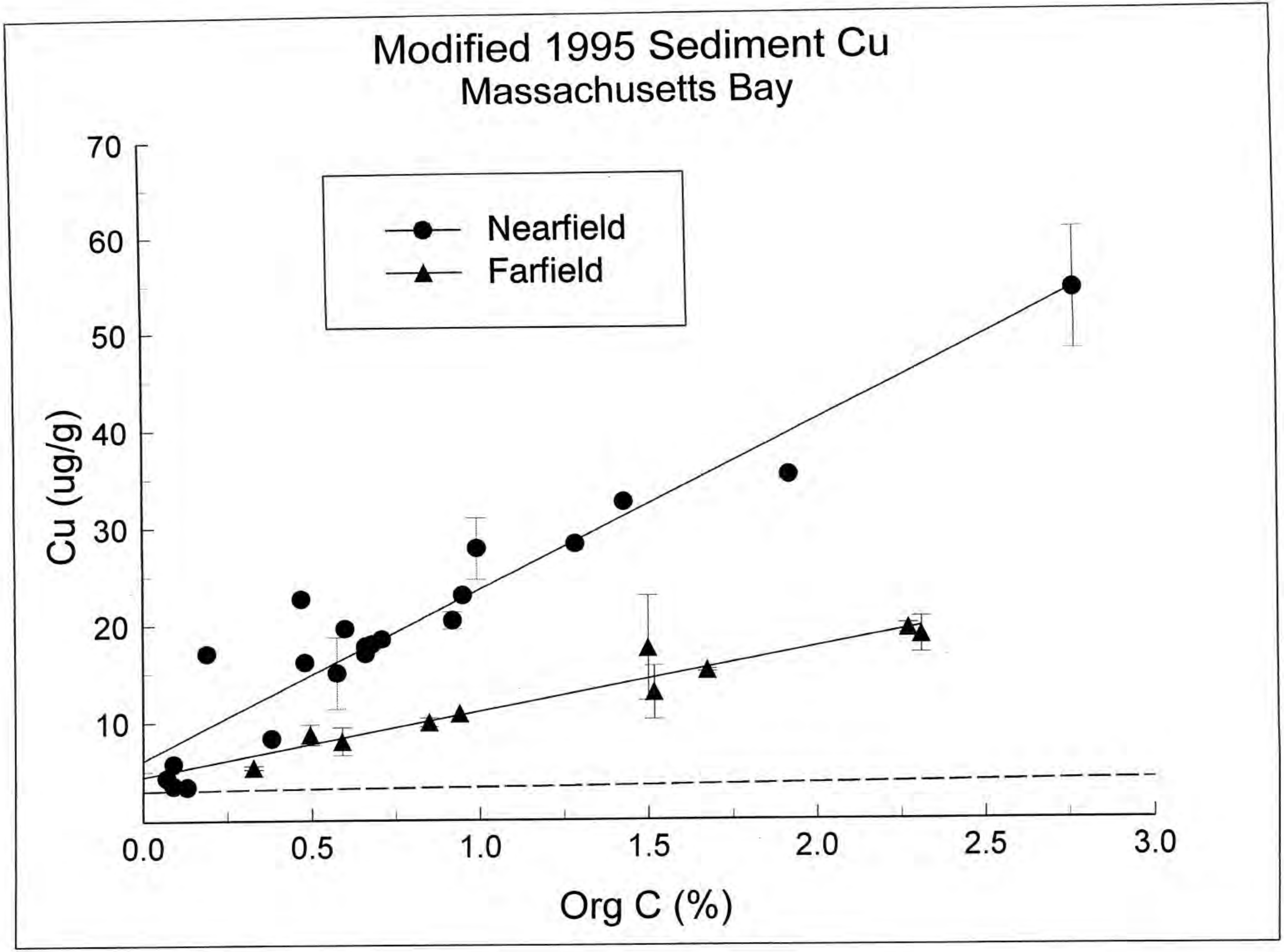

C. perfringens vs. C org
1994
Nearfield
Farfield
FF13
FF12
FF10
C. per (No./g dry weight)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
% Org C

C. perfringens vs. C org
1994 Modified

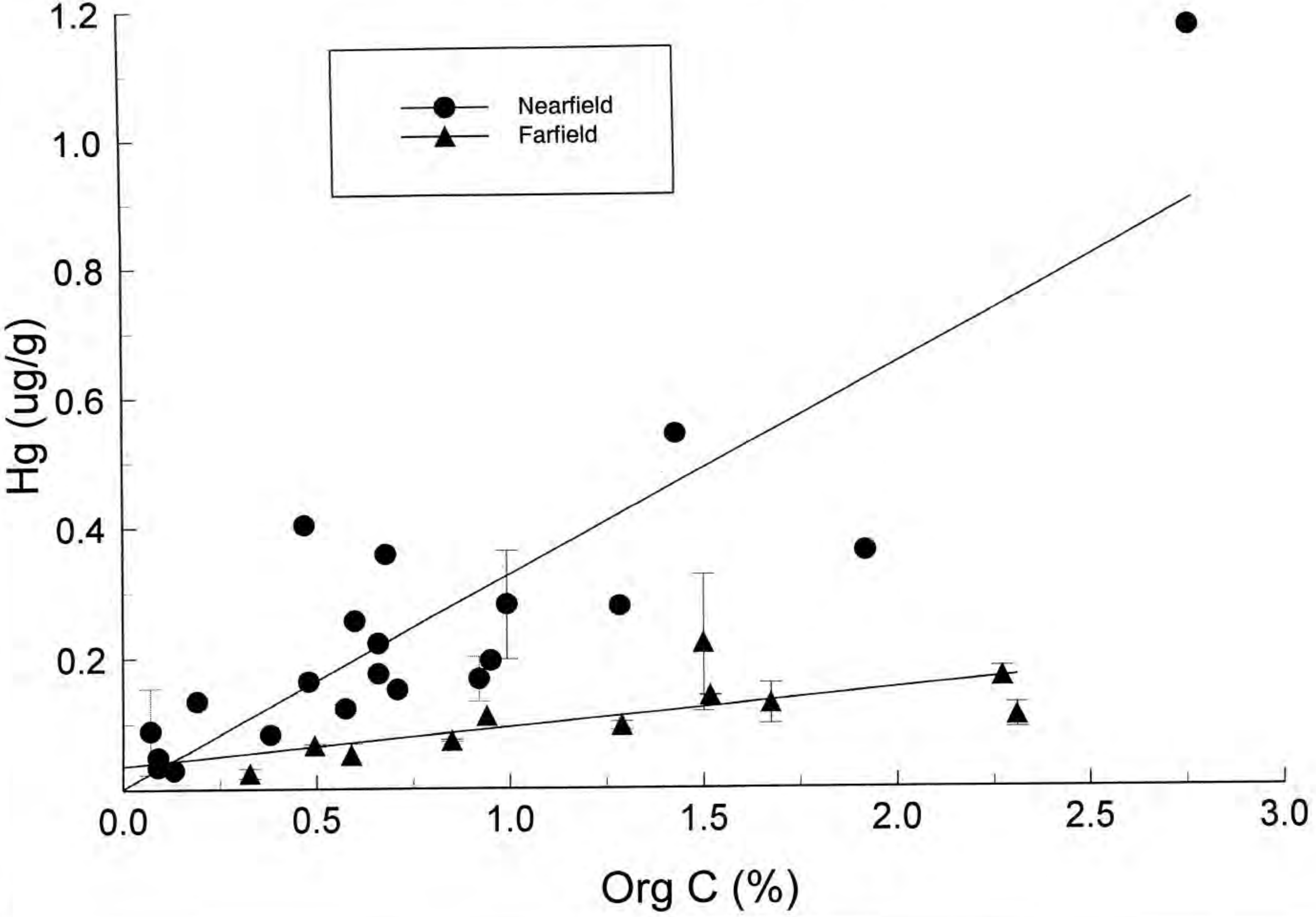


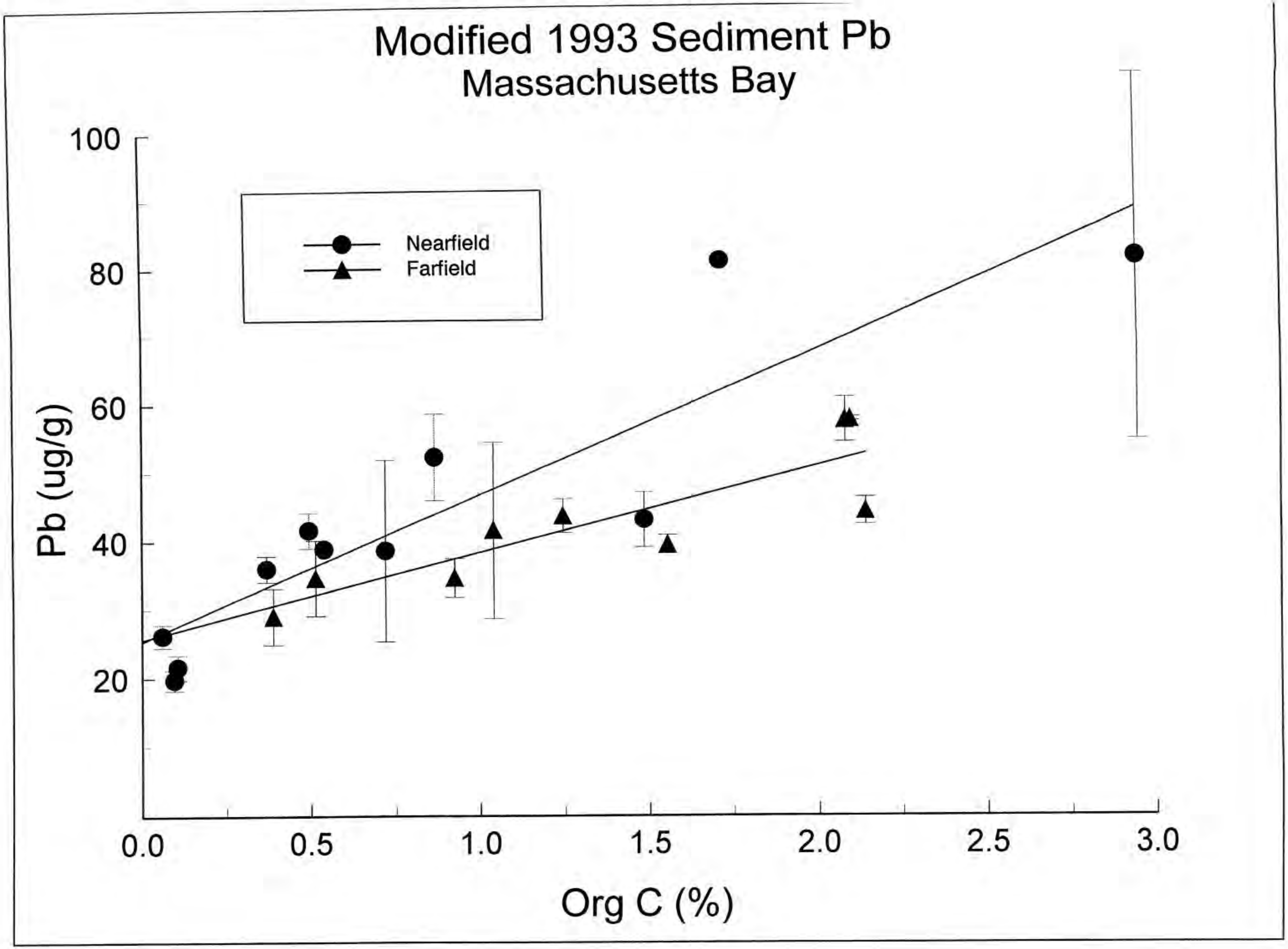

1995 Sediment Ag
Massachusetts Bay
Nearfield
Farfield
Ag (ug/g)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Org C (%)


Modified 1995 Sediment Ag
Massachusetts Bay
Nearfield
Farfield
Ag (ug/g)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Org C (%)


Modified 1995 Sediment Cu
Massachusetts Bay
Nearfield
Farfield
Cu (ug/g)
70
60
50
40
30
20
10
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Org C (%)

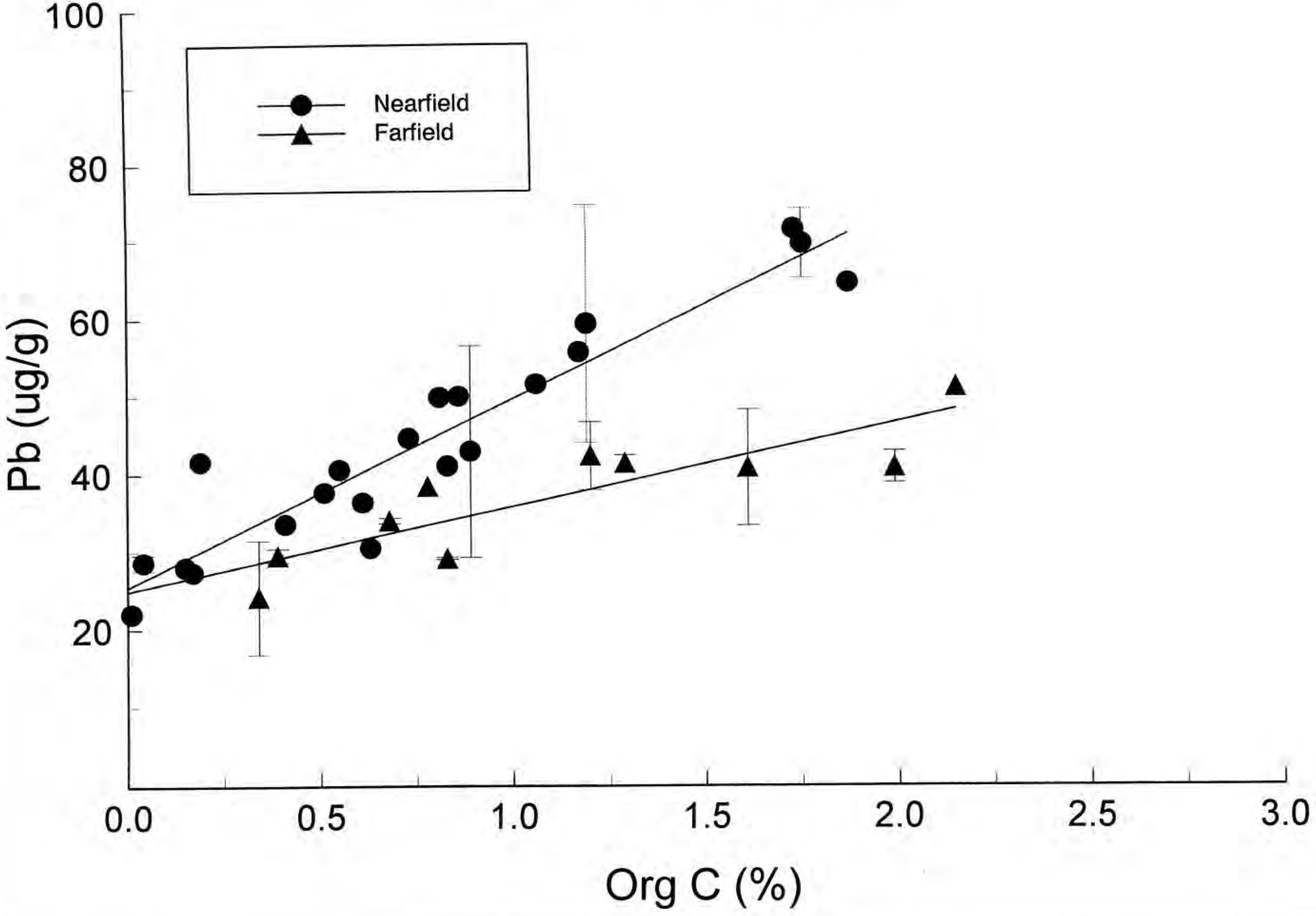
Modified 1995 Sediment Hg
Massachusetts Bay

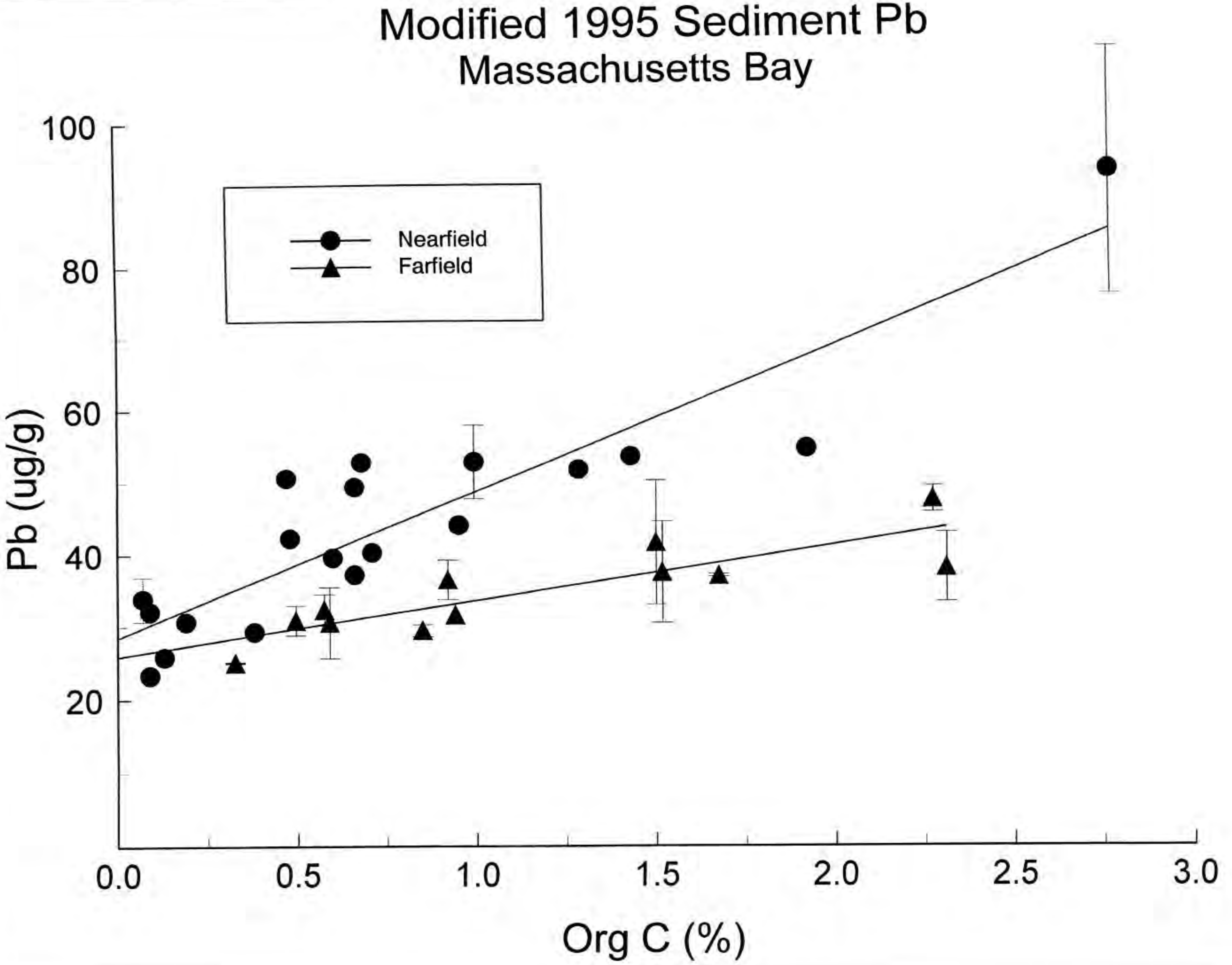


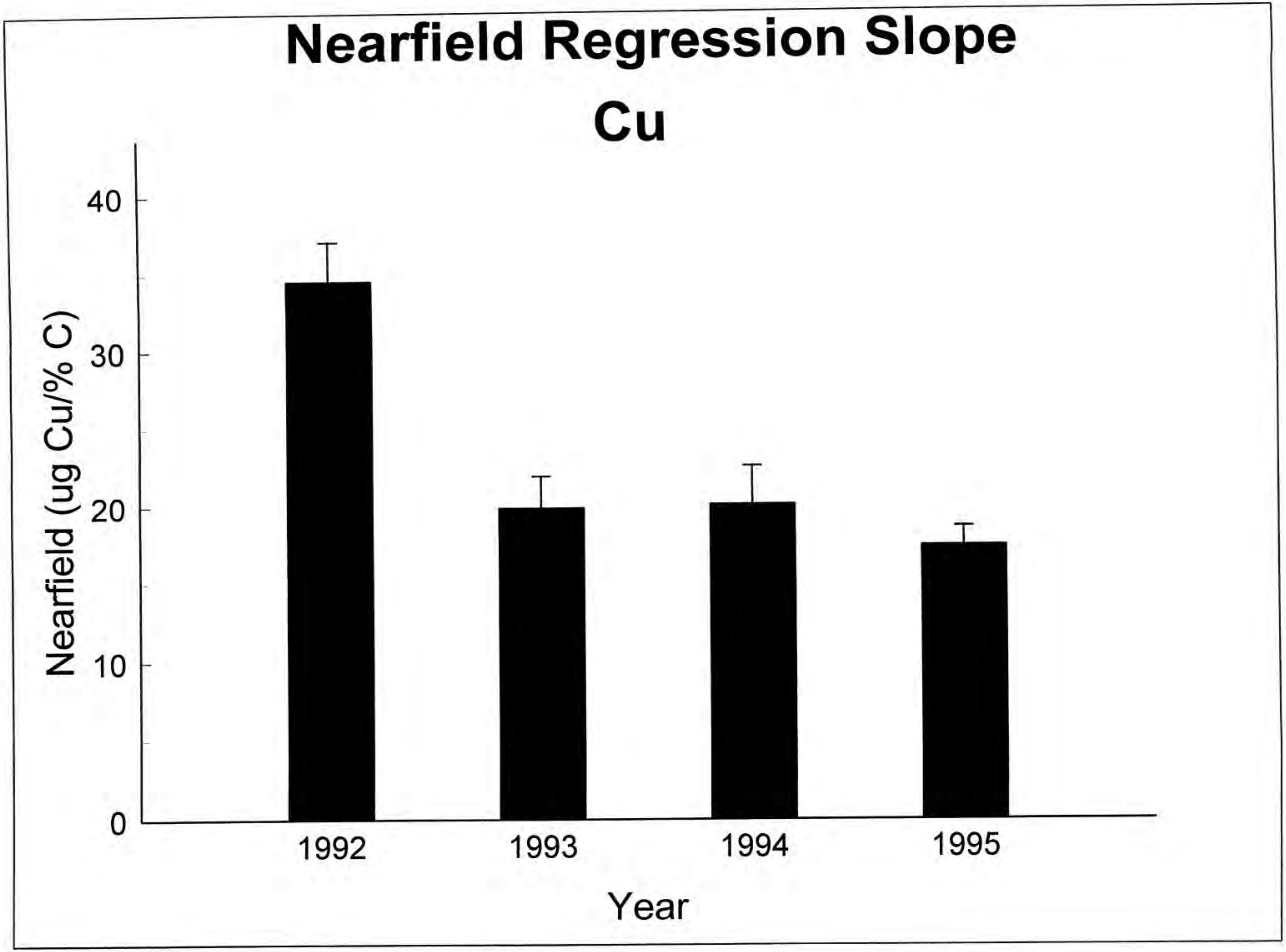


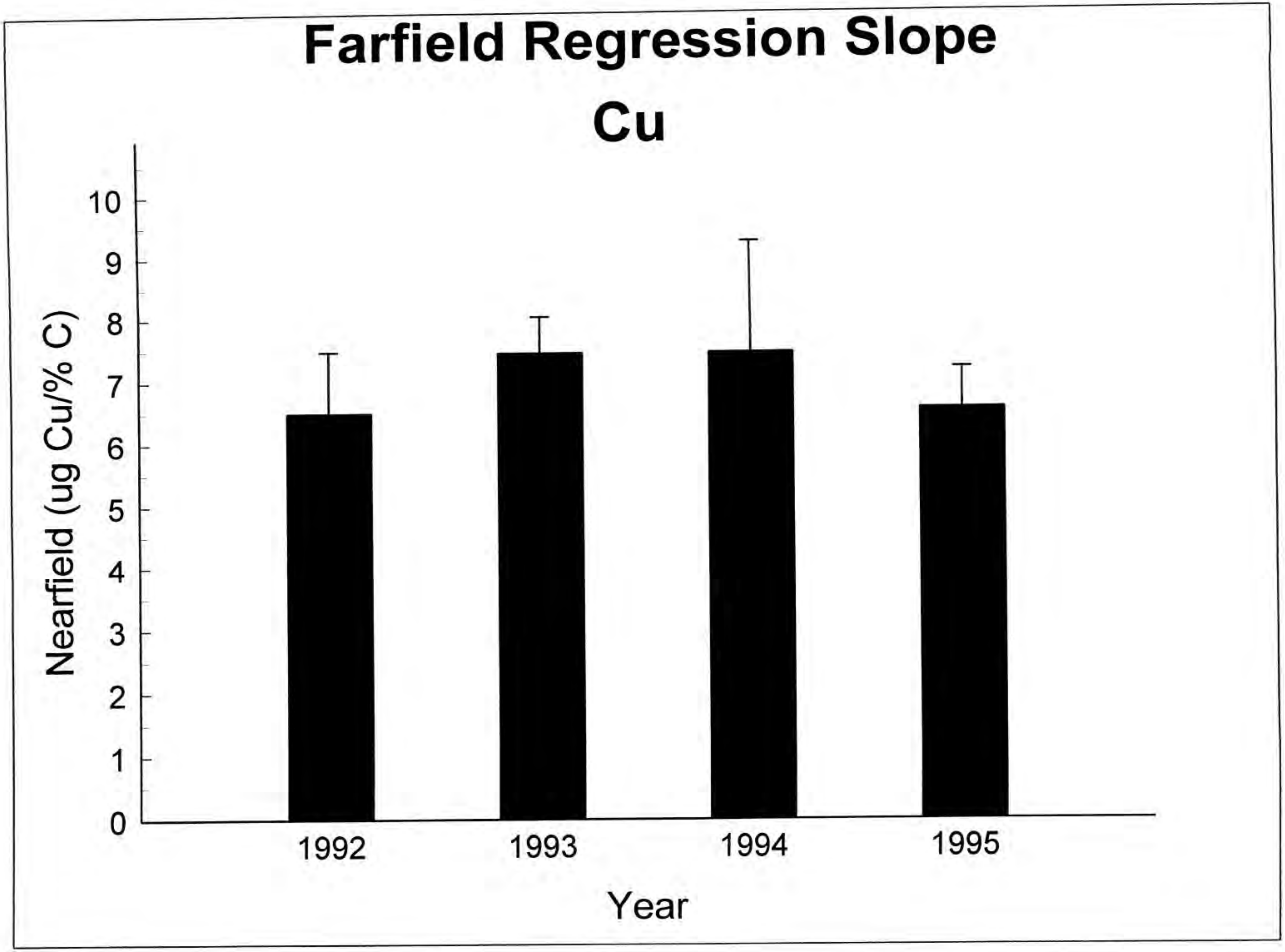
Modified 1993 Sediment Pb
Massachusetts Bay

Modified 1994 Sediment Pb
Massachusetts Bay

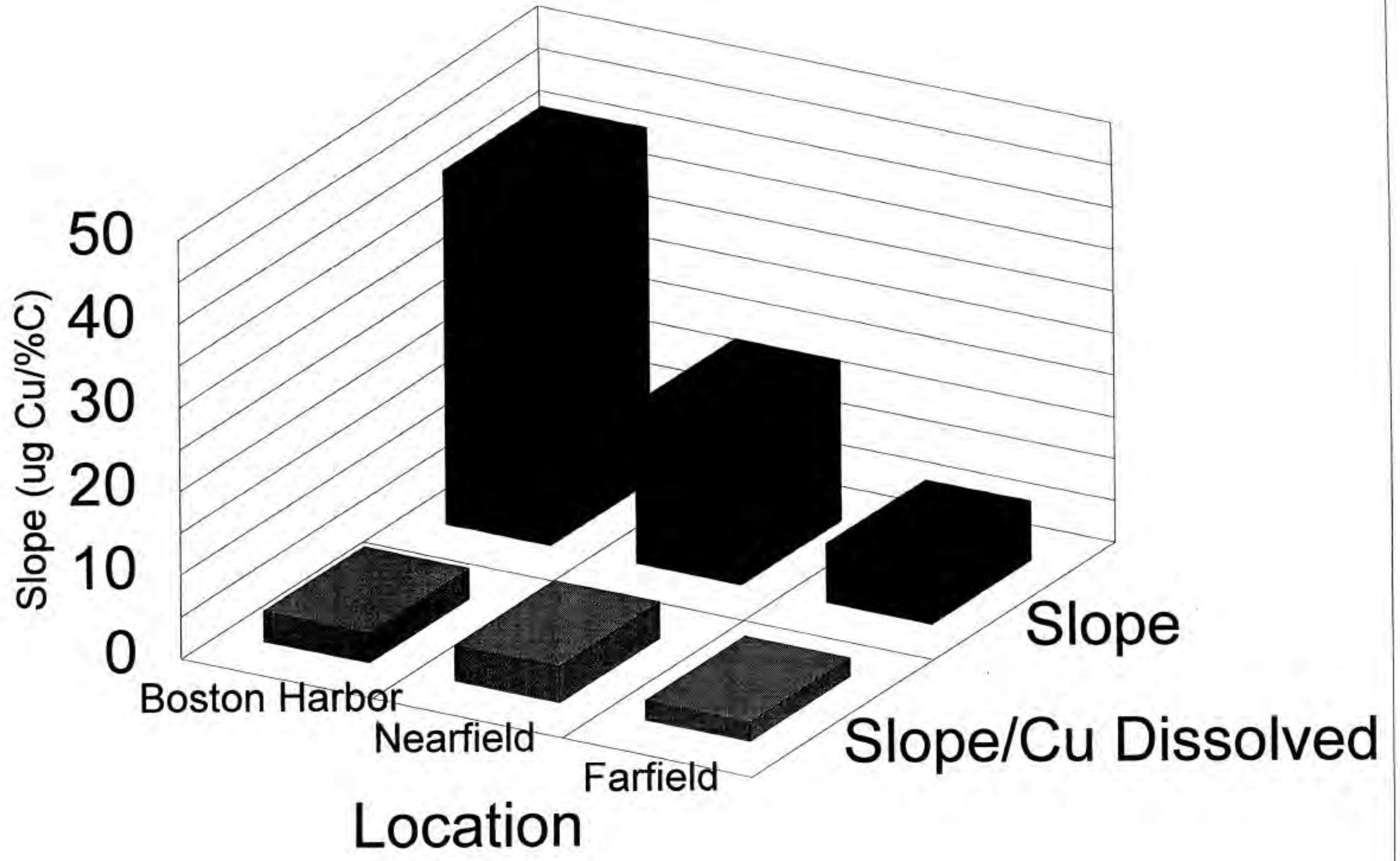



Modified 1995 Sediment Pb
Massachusetts Bay
Nearfield
Farfield
Pb (ug/g)
100
80
60
40
20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Org C (%)

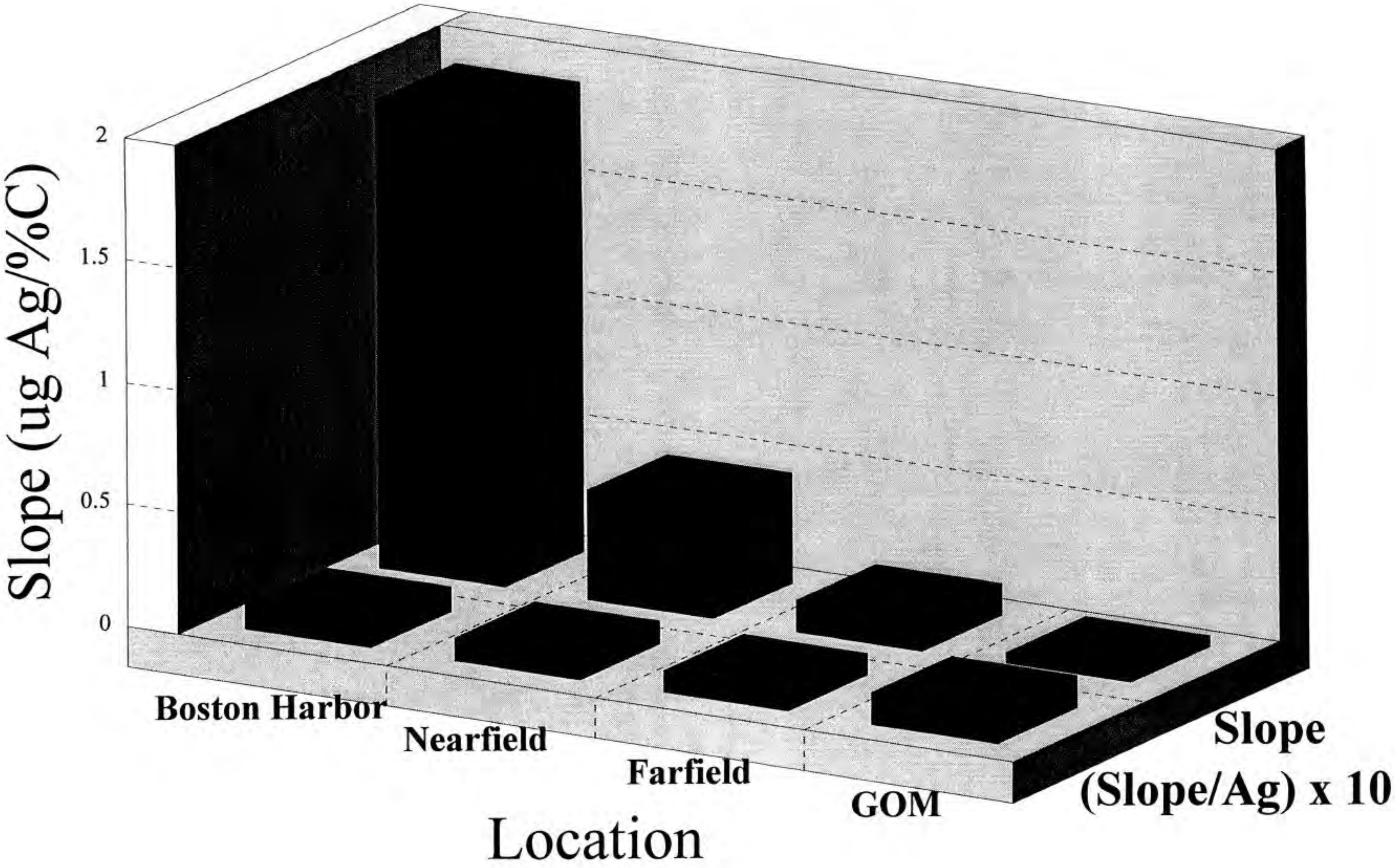

Nearfield Regression Slope
Cu
Nearfield (ug Cu/% C)
40
30
20
10
0
1992
1993
1994
1995
Year


Farfield Regression Slope
Cu
Nearfield (ug Cu/% C)
0
1
2
3
4
5
6
7
8
9
10
1992
1993
1994
1995
Year

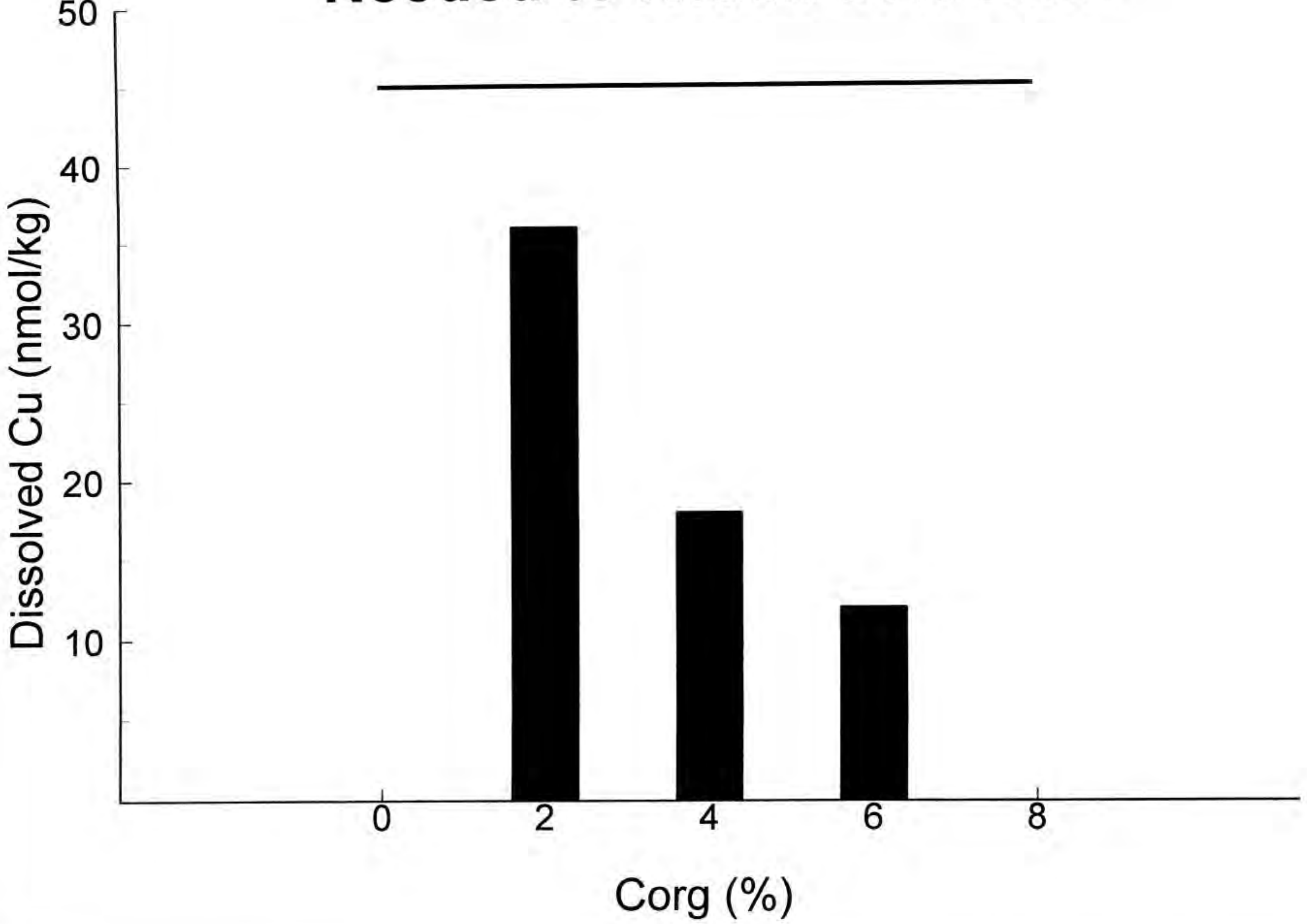
Cu Regression Slopes



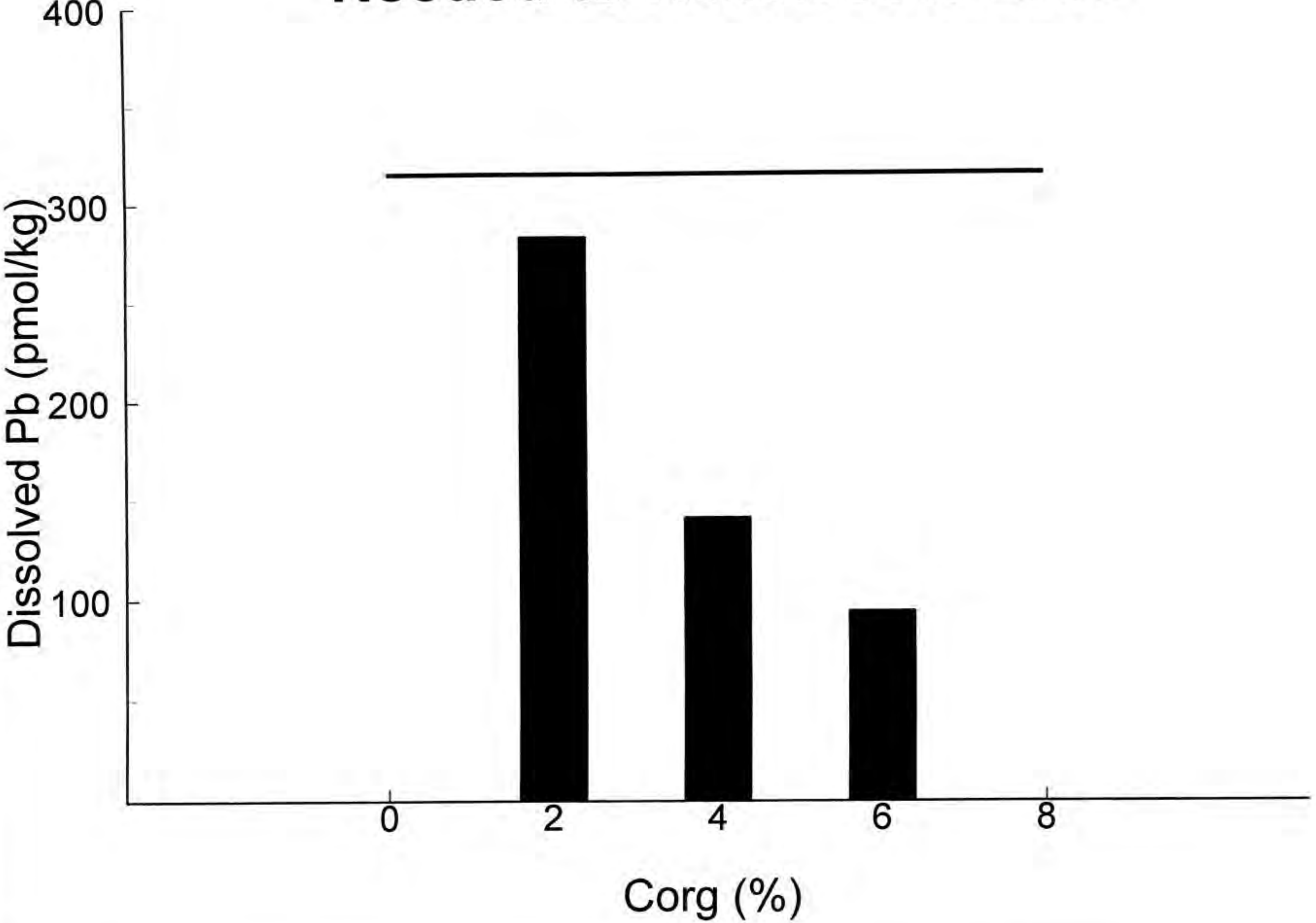
Ag Regression Slopes

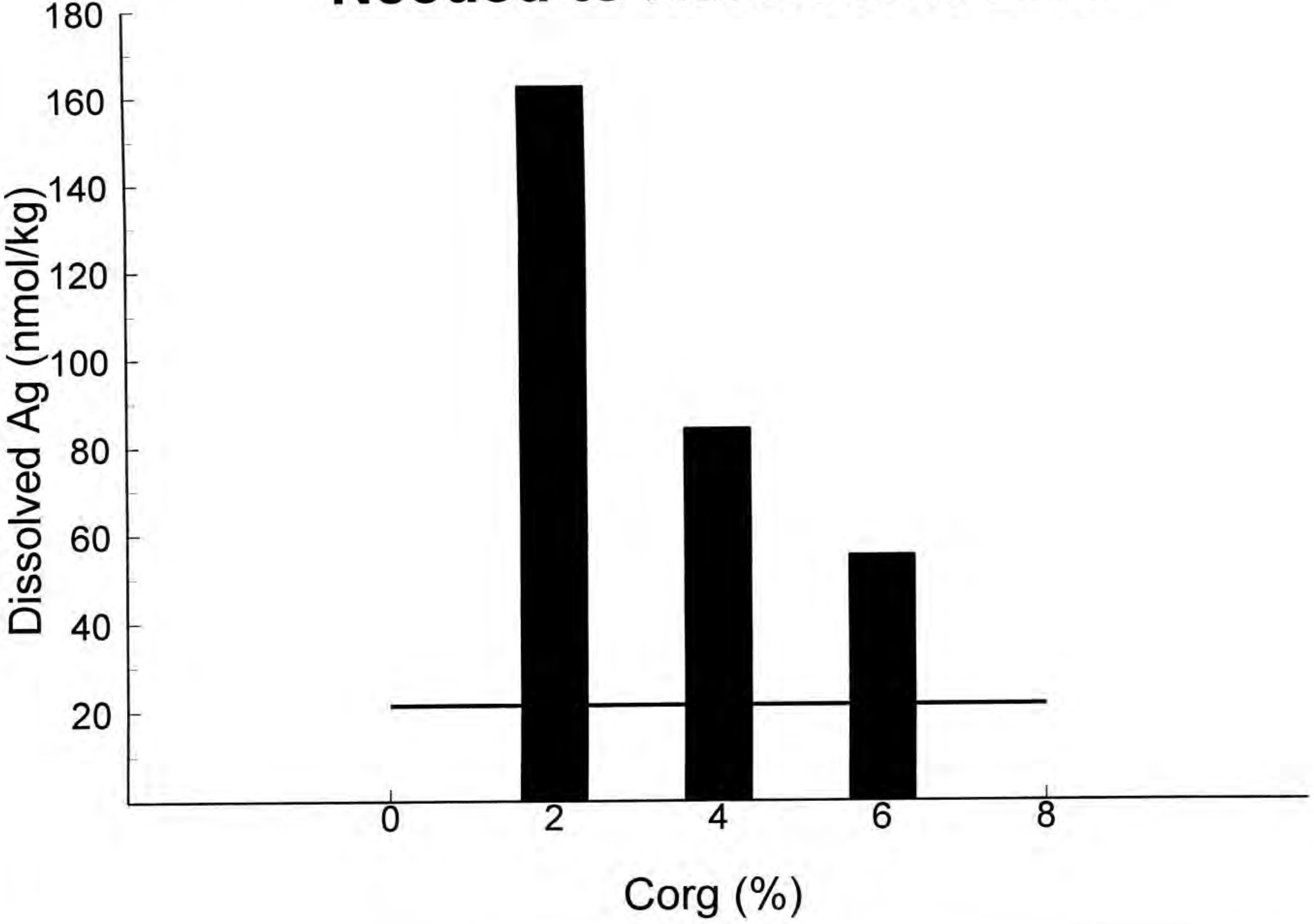


Interdependence of Corg and Cu Dissolved Needed to Reach 90% ERM



Interdependence of Corg and Pb Dissolved Needed to Reach 90% ERM





Interdependence of Corg and Ag Dissolved Needed to Reach 90% ERM

ASSUMPTIONS REVISITED

- **{M} in pore waters and overlying water column may be different but for slowly accumulating surface oxic sediments, these differences may not be great.**

- **{L} for the same reasons may also not be greatly different in the two environments.**

- **However both {M} and {L} may be different at the sediment-water interface under quiescent conditions and may cause short-term, highly local spatial heterogeneity.**

- **The proposed relationship between sediment organic matter and free metal ion concentrations assumes there is a more or less homogeneous quality of the organic matter in the surface sediments. This may be optimistic but:**
    - **Is consistent with the relatively long residence time of the surface sediments**
    - **Current understanding of the affinity of metals for organic matter relative to other solid phases in coastal sediments**
    - **Experimental evidence and current thoughts regarding the presence of mono- or multi- layer coatings of mineral surfaces in sediments by organic matter.**
    - **Can explain the metal content of sediments over a wide variety of environmental conditions.**

SOME FURTHER THOUGHTS

- **Sediment quality (relative to ERMs) are clearly not consistent with existing water quality criteria.**
- **While not perfect and entirely intellectually satisfying, the proposed relationship between the organic content of the sediments, overlying water column concentrations (activity) of metals, and sediment metal concentration may provide a more sensitive basis for assessing changes in sediment quality then currently available.**
- **The existing data on effluent loadings and expected ambient water column concentrations, even at the primary treatment level, suggests that ERMs for most metals are unlikely to be exceeded provided organic matter concentrations in the sediments do not become excessive.**
- **Possible exceptions to this may occur in localized areas where sediment accumulation of organic matter results in anoxic conditions near the sediment-water interface. Metal contents of the sediments may be elevated over that expected based on ambient water column concentrations and sediment organic C due to direct diffusive fluxes into the sediment under these conditions.**
- **Caution should be exercised in interpreting reduction in surface sediment concentrations of metals as indicative of reduced source loadings of metals. Much of the change may reflect reduced organic matter loading to the sediments and concurrent re-oxygenation and loss of metals held in acid-volatile sulfide phases, and not a reduction in metal loading to the system.**

RECOMMENDATIONS

- **To improve resolution of potentially important patterns analyze all sample variables from the same homogenized sample, i.e. metals, Corg, grain size etc.**

- **Test some of the hypotheses inherent in the assumptions made in applying this model. Determination of sorption isotherms under well-defined conditions could enhance the confidence in predicting sediment quality using the variables proposed.**

- **Ambient water column concentrations are an integral part of the "story" and are not well characterized in the deeper waters of the Bay.**

- **Interpretation of down core profiles as an indicator of change will require careful assessment of the relative importance of decreased organic matter loading and decreased metal inputs into the system.**

APPENDIX C-5

Eric Butler
ENSR

SEDIMENT ORGANICS

DATA ARE VERY COMPARABLE

TOTAL ORGANICS DO NOT EXCEED 90 % OF NOAA ER-M VALUES

TOTAL ORGANICS IN BASE AREA DO NOT EXCEED 90 % OF AVAILABLE EPA CRITERIA

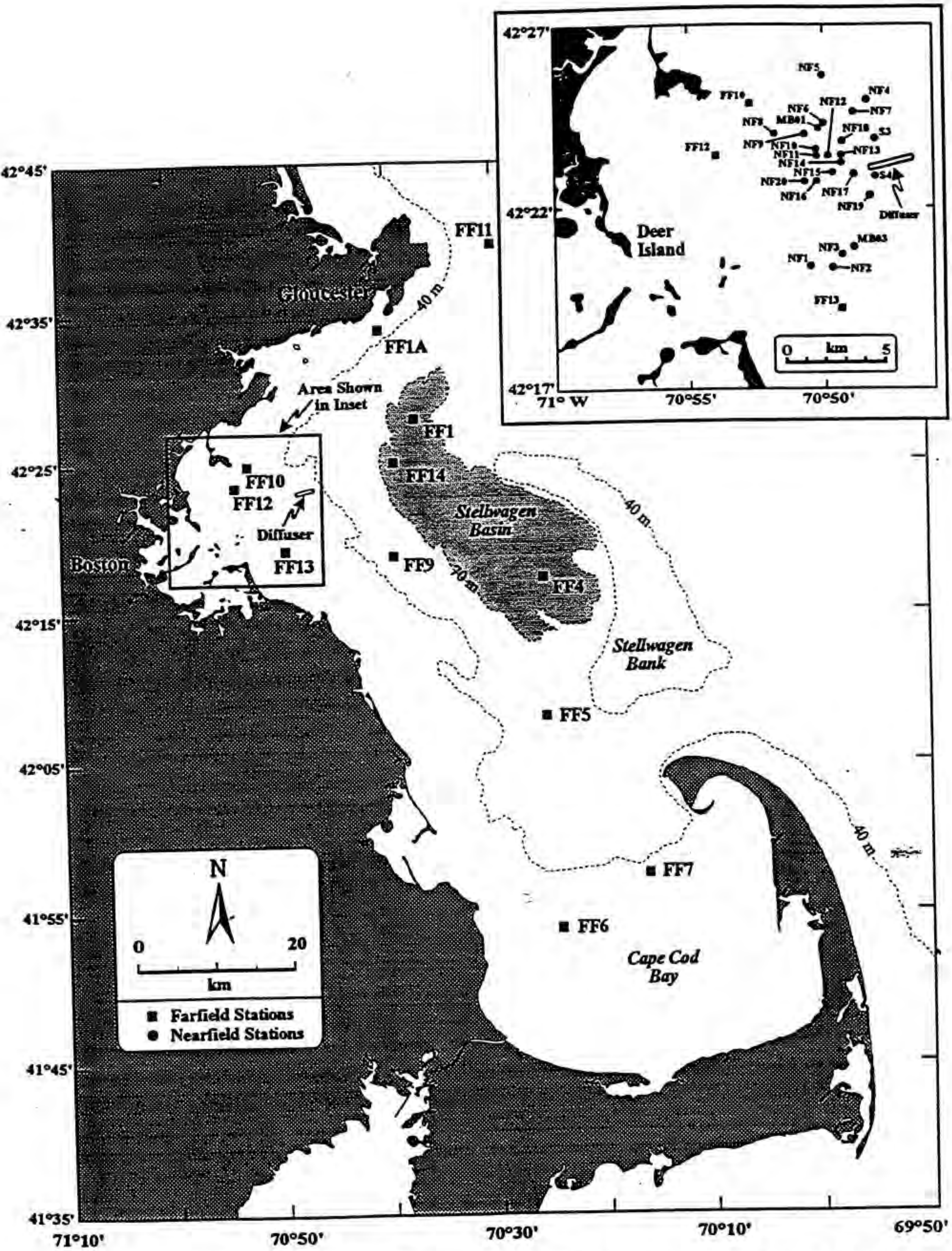


Figure 1. Location of outfall monitoring stations in Massachusetts and Cape Cod Bays.

TABLE 3

Effluent Chemistry Analytes

Metals

Ag silver
Cd cadmium
Cu copper
Cr chromium
Hg mercury
Mo molybdenum
Ni nickel
Pb lead
Zn zinc

Polychlorinated biphenyls

2,4,-Cl_2(8)
2,2',5-Cl_3(18)
2,4,4'-Cl_3(28)
2,2',3,5'-Cl_4(44)
2,2',5,5'-Cl_4(52)
2,3',4,4'-Cl_4(66)
3,3',4,4'-Cl_4(77)
2,2'4,5,5'-Cl_5(101)
2,3,3',4,4'-Cl_5(105)
2,3',4,4'5-Cl_5(118)
3,3',4,4',5-Cl_5(126)
2,2',3,3,4,4'-Cl_6(128)
2,2',3,4,4',5-Cl_6(138)
2,2'4,4',5,5'-Cl_6(153)
2,2'3,3,4,4',5-Cl_7(170)
2,2',3,4,4',5,5'-Cl_7(180)
2,2',3,4,5,5',6-Cl_7(187)
2,2',3,3',4,4',5,6-Cl_8(195)
2,2',3,3'4,4',5,5',6-Cl_9(206)
Decachlorobiphenyl-Cl_{10}(209)

Linear alkyl benzenes (LAB)

phenyl decanes
phenyl undecanes
phenyl dodecanes
phenyl tridecanes
phenyl tetradecanes

Polynuclear aromatic hydrocarbons (PAH)

naphthalene
C_1-naphthalenes
C_2-naphthalenes
C_3-naphthalenes
acenaphthylene
acenaphthene
fluorene
C_1-fluorenes
C_2-fluorenes
C_3-fluorenes

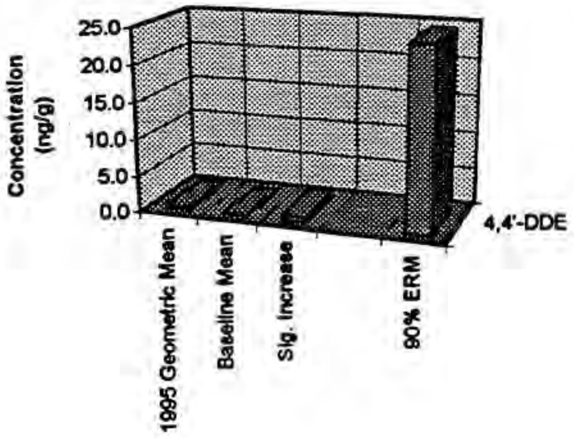
PAH (continued)

anthracene
phenanthrene
C_1-phenanthrenes/anthracene
C_2-phenanthrenes/anthracene
C_3-phenanthrenes/anthracene
C_4-phenanthrenes/anthracene
dibenzothiophene
C_1-dibenzothiophenes
C_2-dibenzothiophenes
C_3-dibenzothiophenes
fluoranthene
pyrene
C_1-fluoranthenes/pyrenes
benzo[*a*]anthracene
chrysene
C_1-chrysene
C_2-chrysene
C_3-chrysene
C_4-chrysene
benzo[*b*]fluoranthene
benzo[*k*]fluoranthene
benzo[*a*]pyrene
dibenzo[*a,h*]anthracene
benzo[*g,h,i*]perylene
indeno[1,2,3-*c,d*]pyrene
perylene
biphenyl
benzo[*e*]pyrene
dibenzofuran
benzothiazole

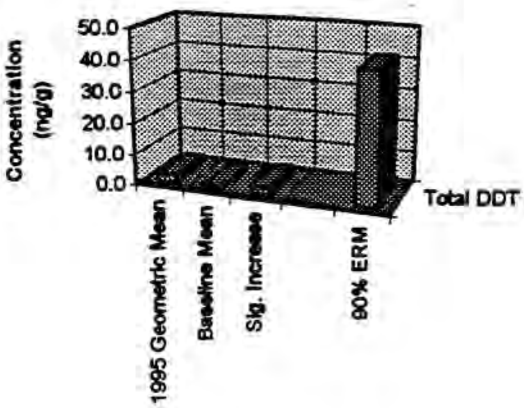
Pesticides

hexachlorobenzene
lindane
heptachlor
aldrin
endrin
heptachlorepoxide
alpha-chlordane
trans-Nonachlor
dieldrin
mirex
o,p'-DDD
p,p'-DDD
o,p'-DDE
p,p'-DDE
o,p'-DDT
p,p'-DDT
DDMU

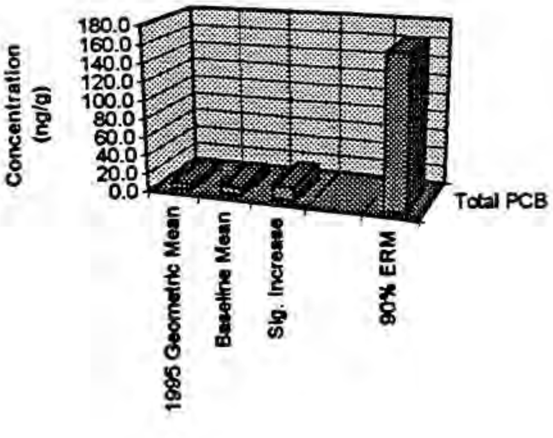
Baseline Mean & 1995 Geometric Mean for 4,4'-DDE



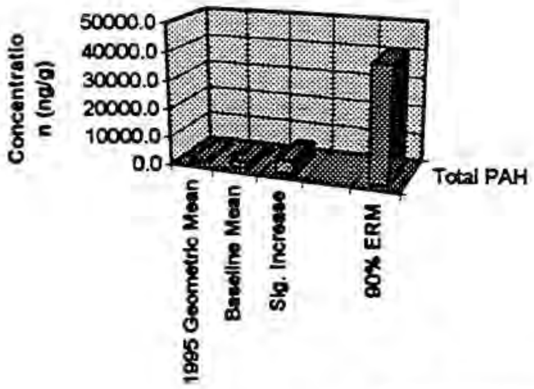
Baseline Mean & 1995 Geometric Mean for Total DDT



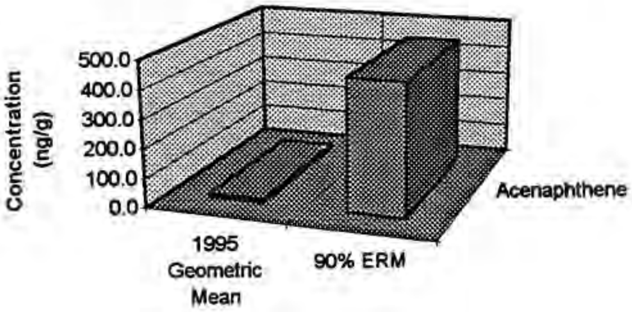
Baseline Mean & 1995 Geometric Mean for Total PCB



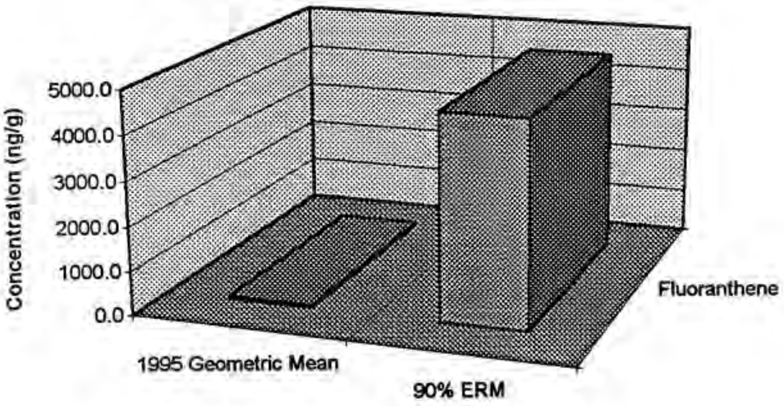
Baseline Mean & 1995 Geometric Mean for Total PAH



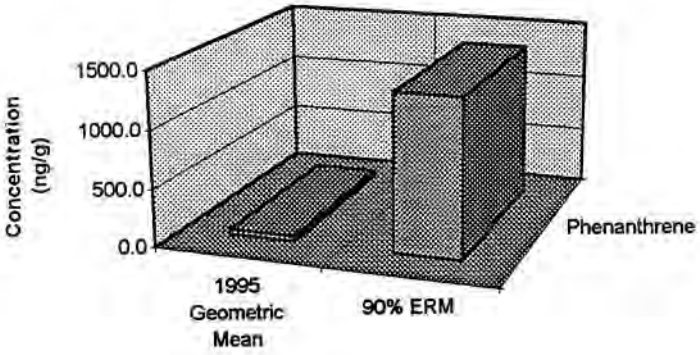
1995 Geometric Mean for Acenaphthene



1995 Geometric Mean for Fluoranthene

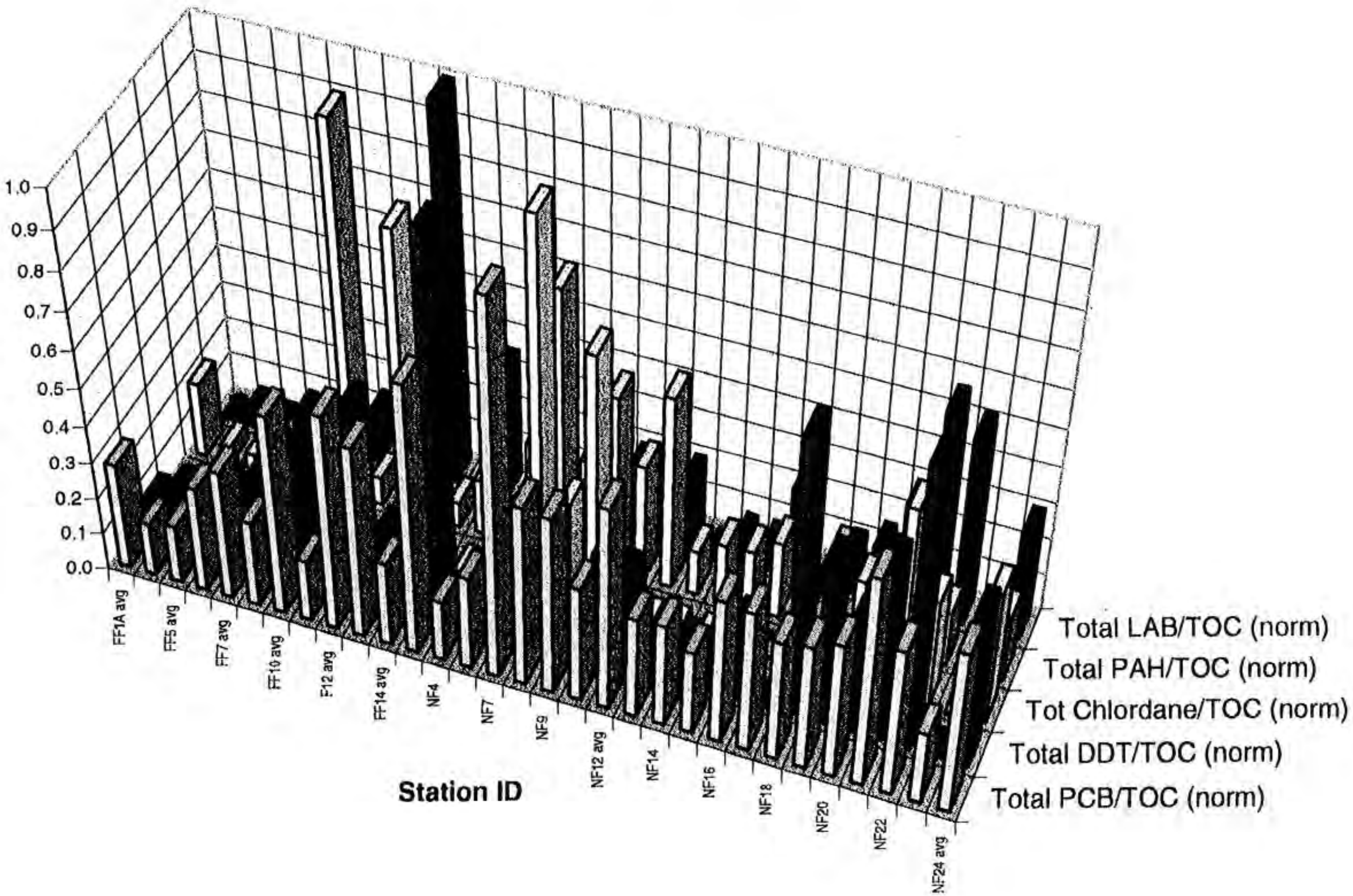


1995 Geometric Mean for Phenanthrene

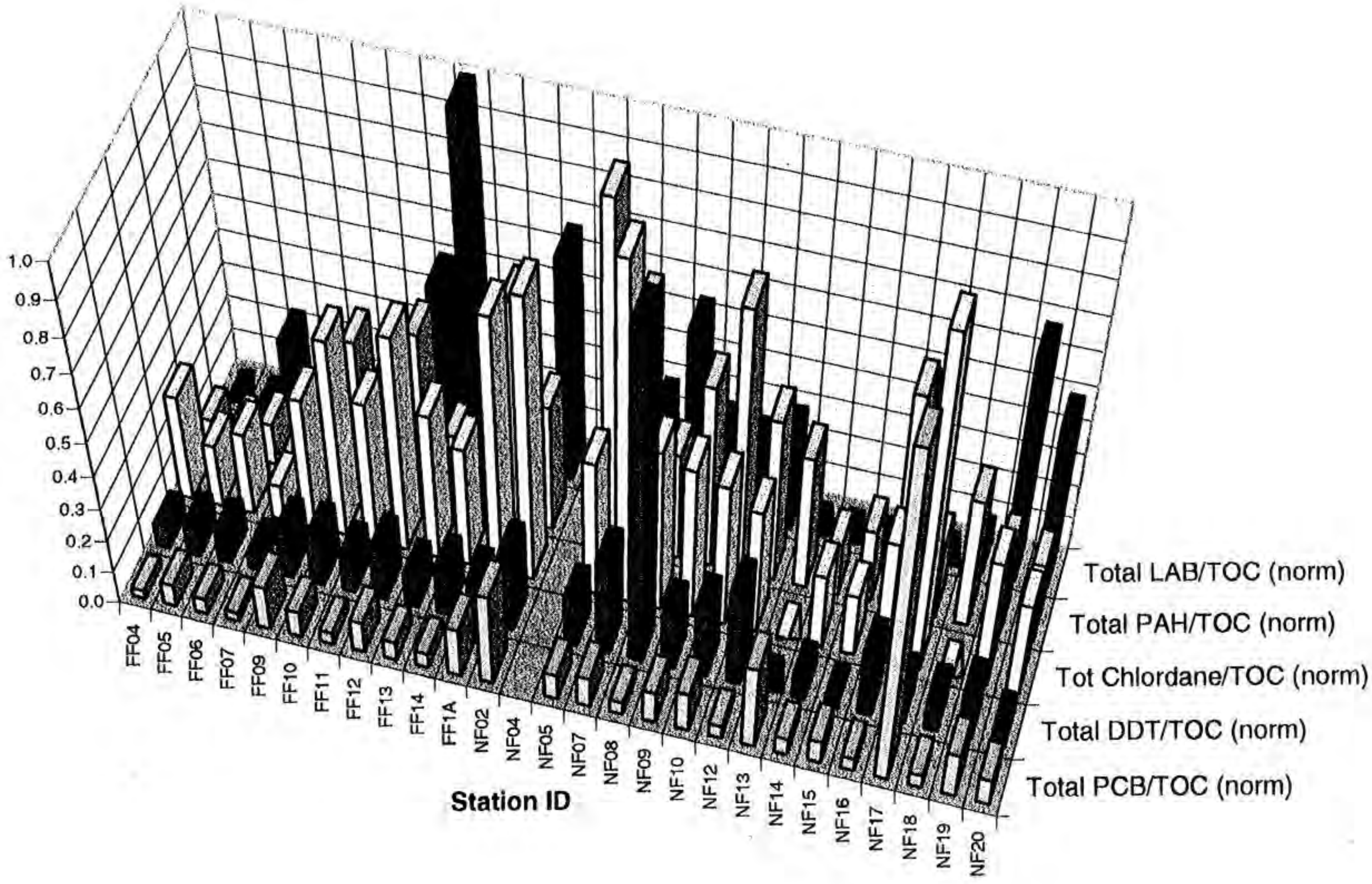


ENSR.

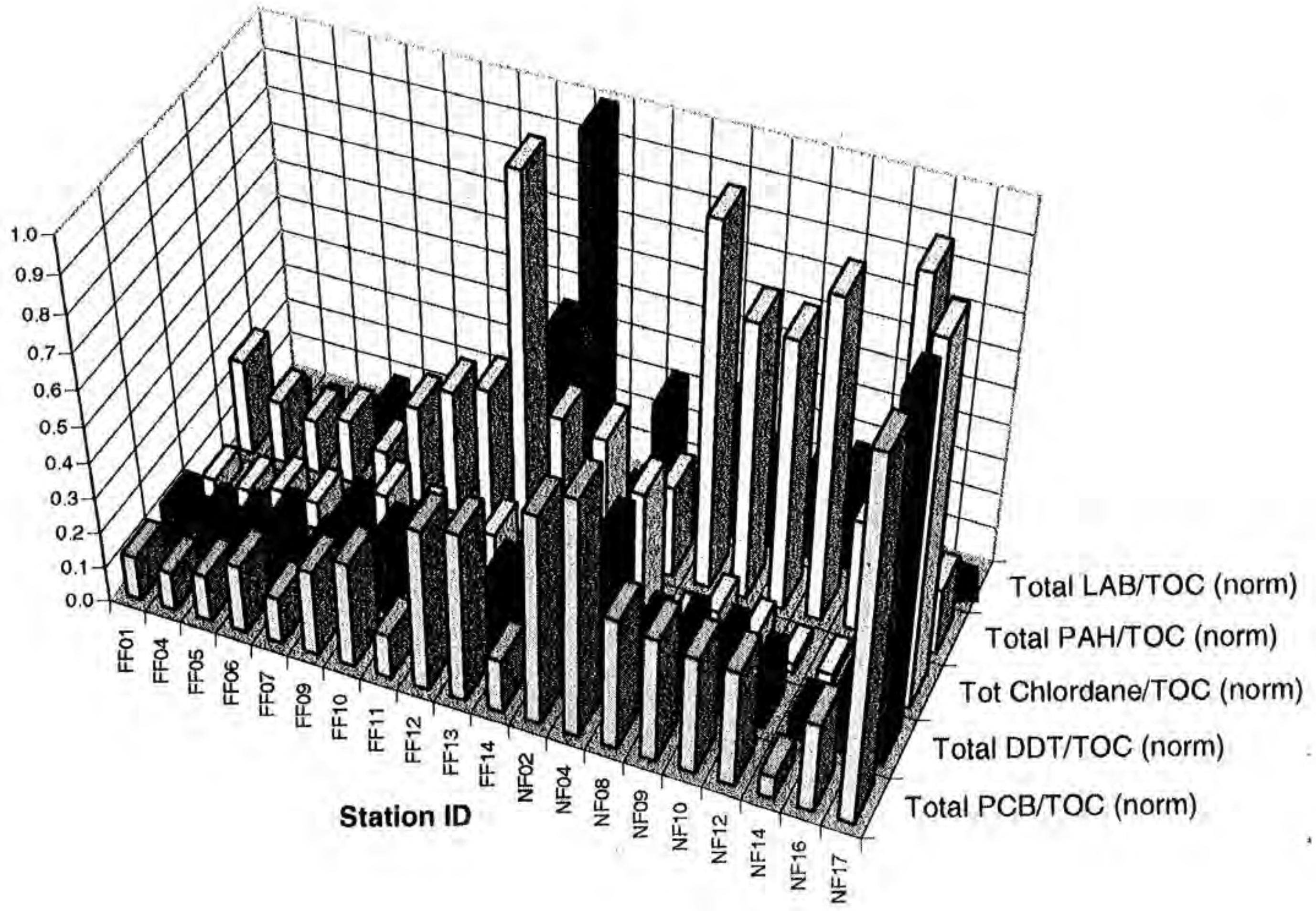
1995 sediment data. TOC-normalized & internally-normalized by analysis type.



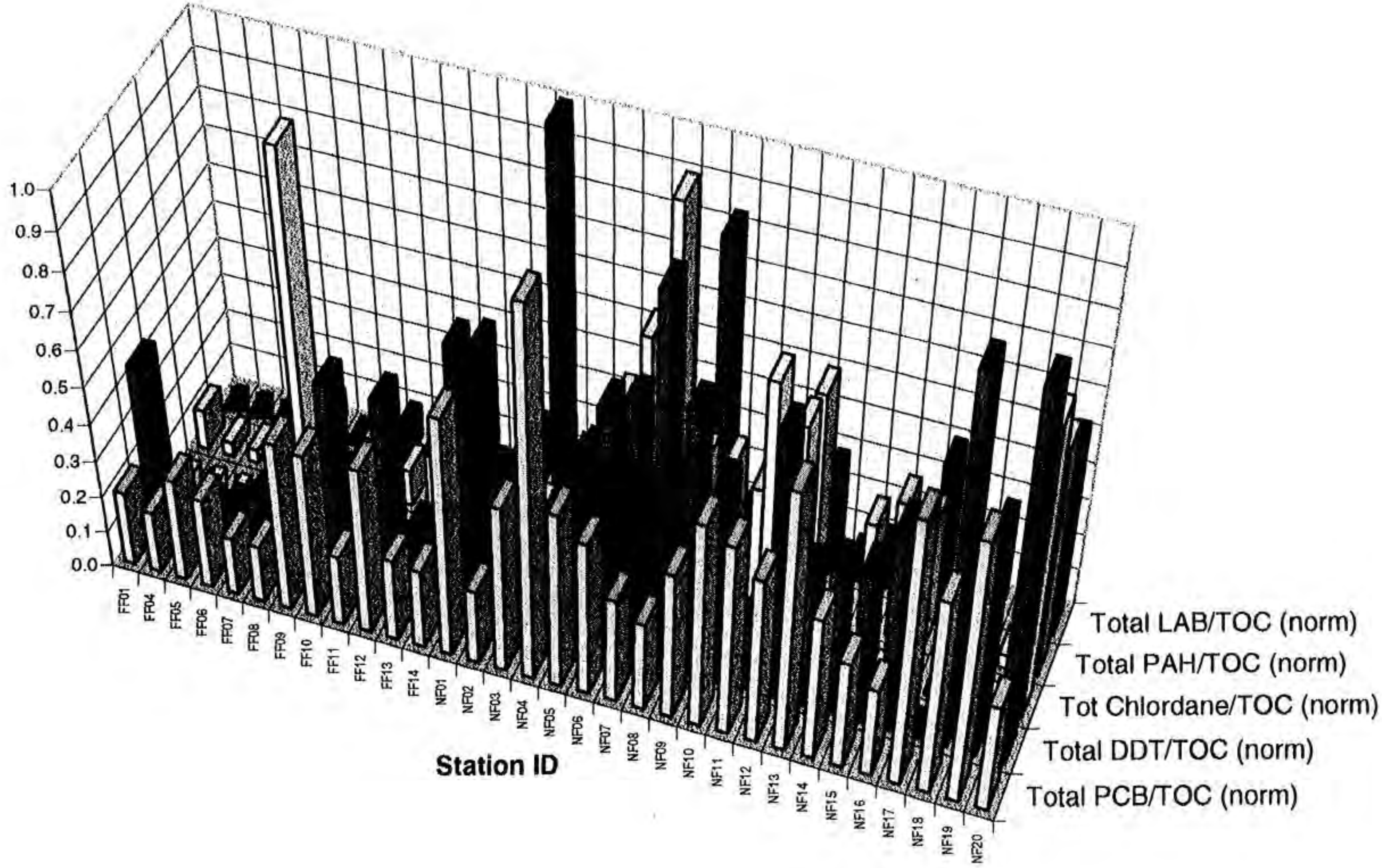
1994 sediment data. TOC-normalized & internally-normalized by analysis type.



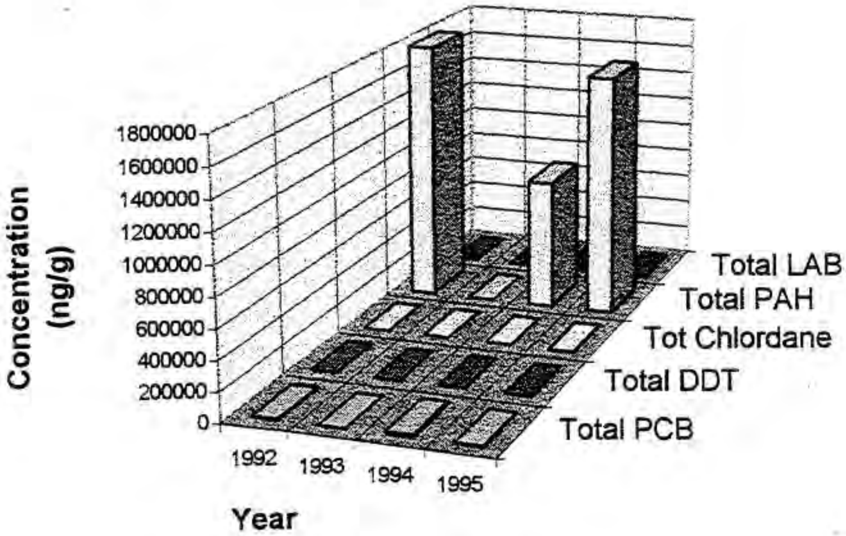
1993 sediment data. TOC-normalized & internally-normalized by analysis type.

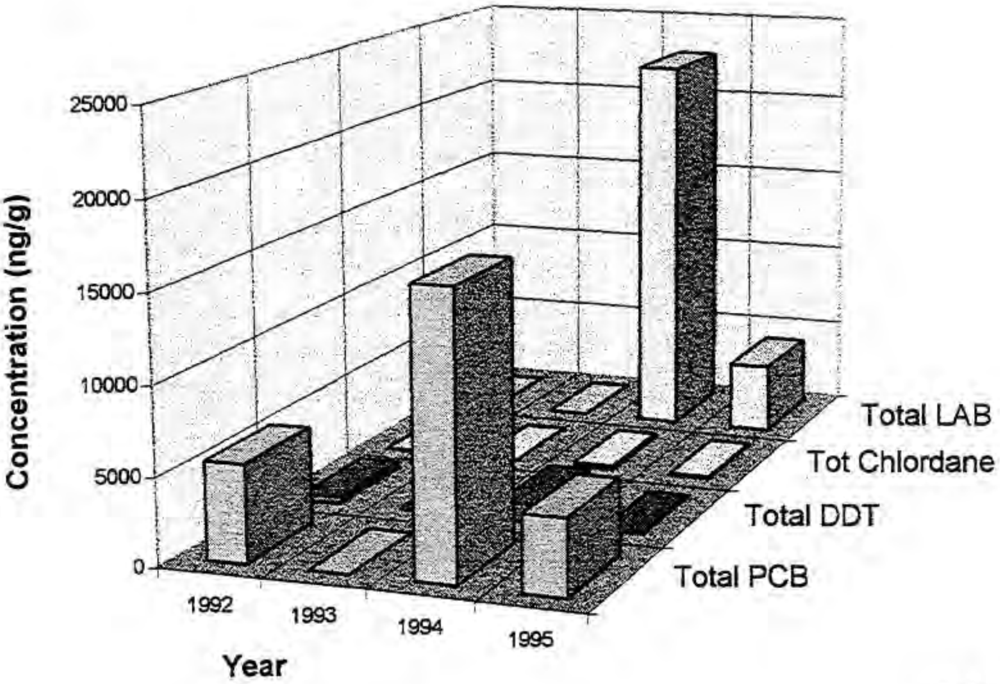


1992 sediment data. TOC-normalized & internally-normalized by analysis type.

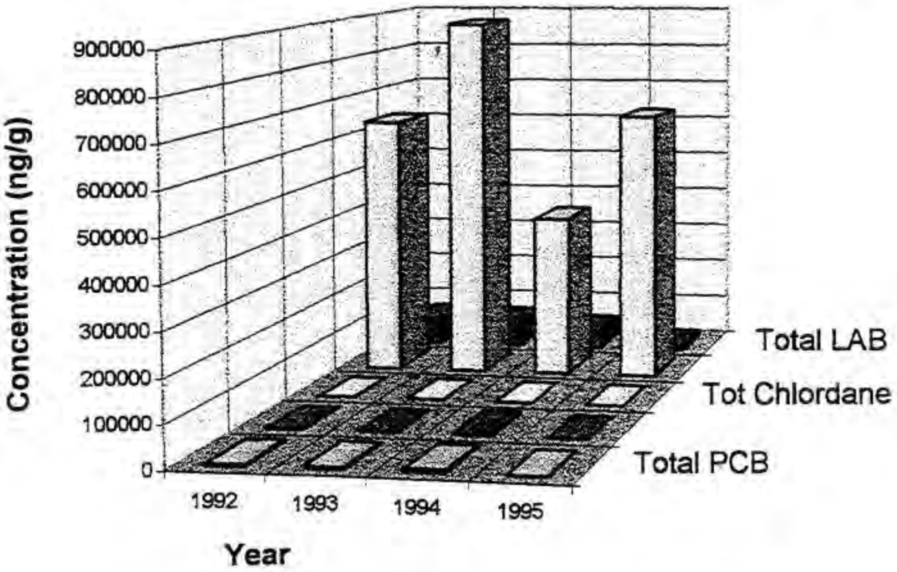


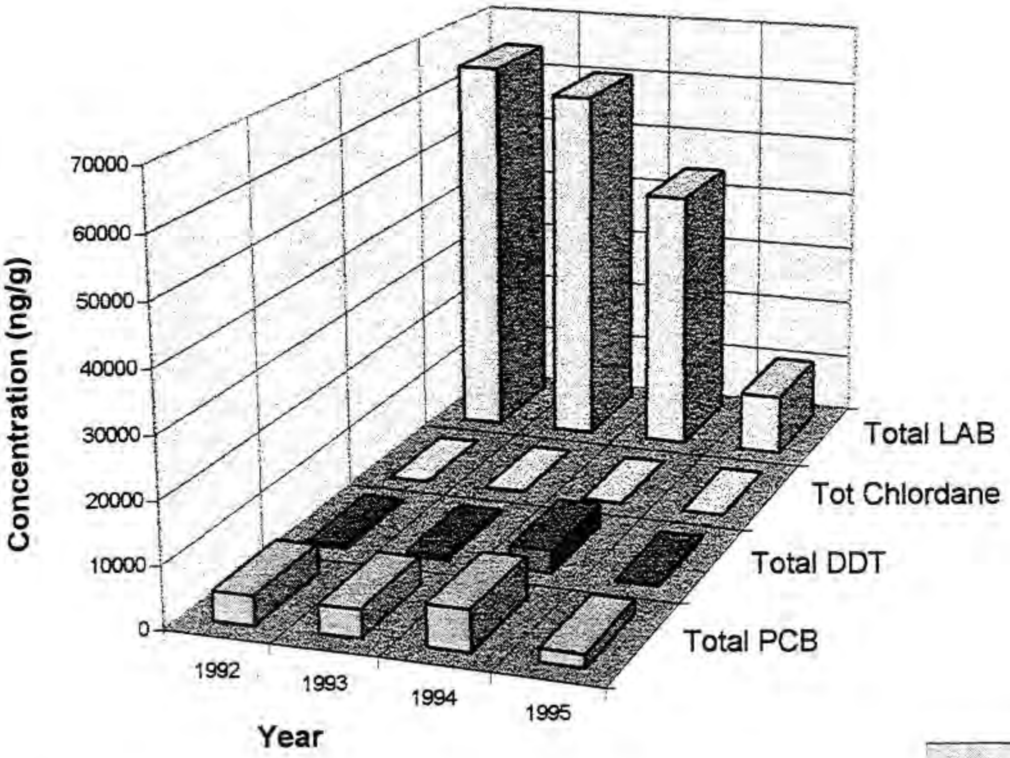
Temporal response of selected TOC-normalized parameters for station NF7



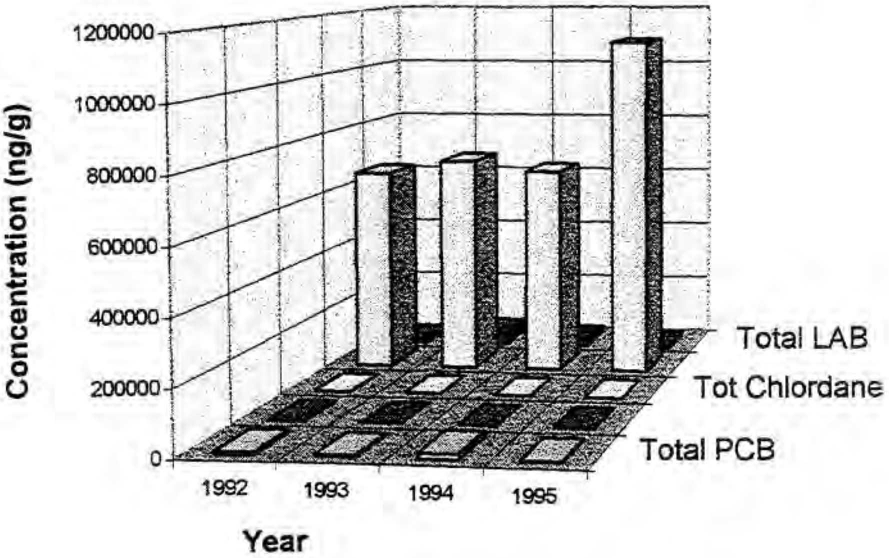


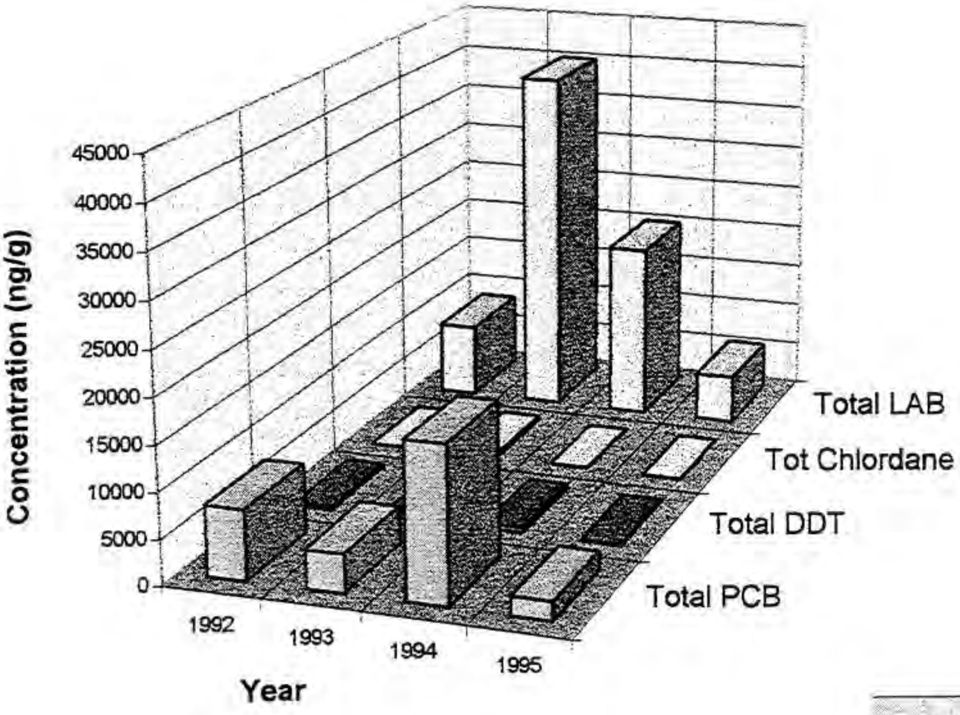
Temporal response of selected TOC-normalized parameters for station NF8



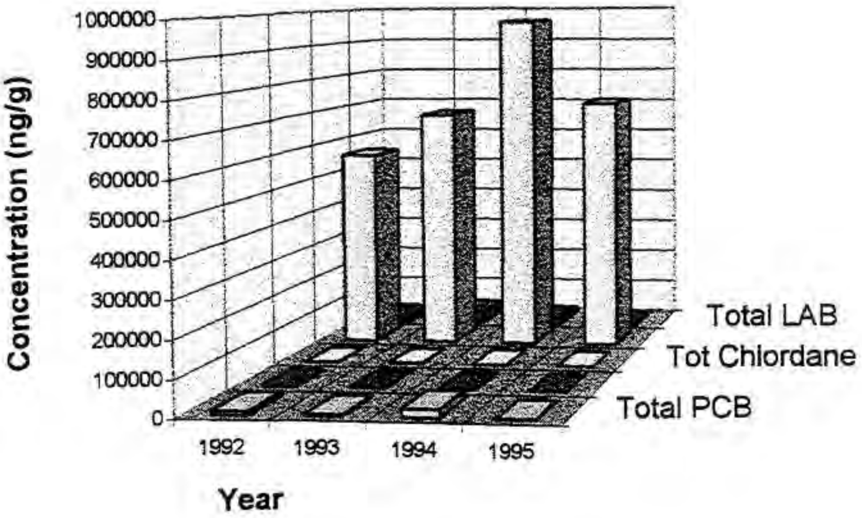


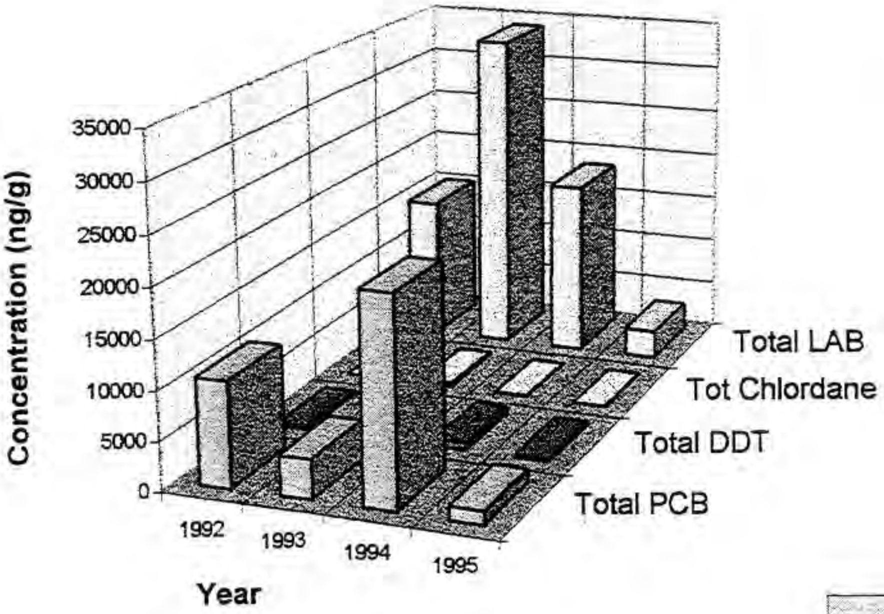
Temporal response of selected TOC-normalized parameters for station NF9



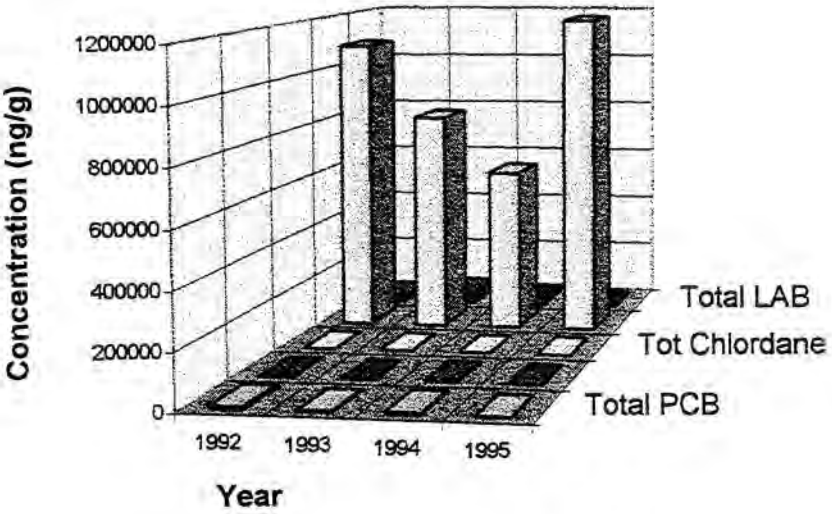


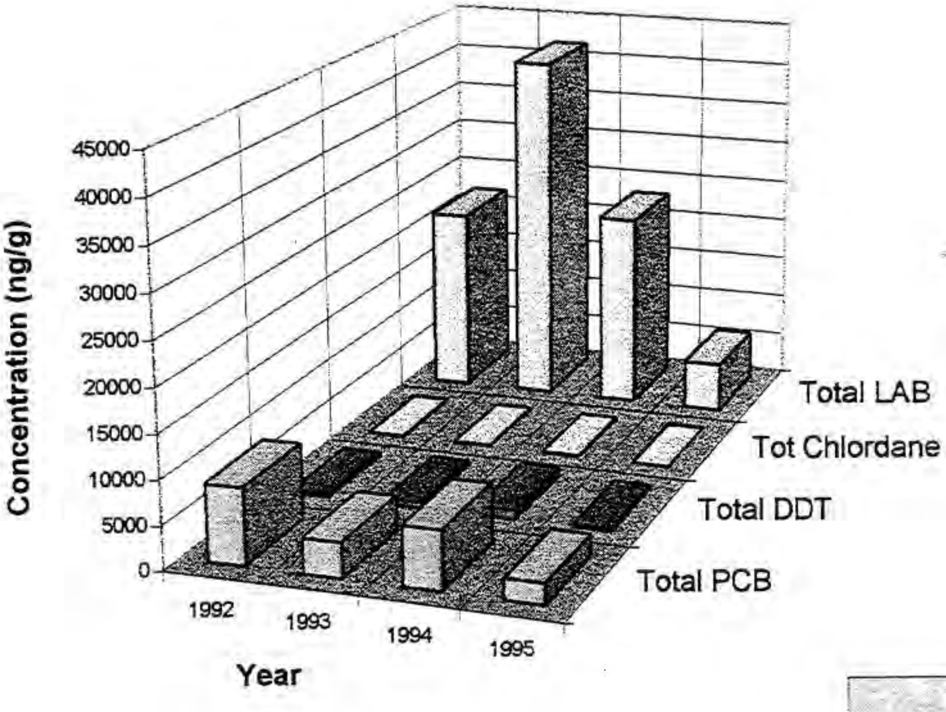
Temporal response of selected TOC-normalized parameters for station NF10



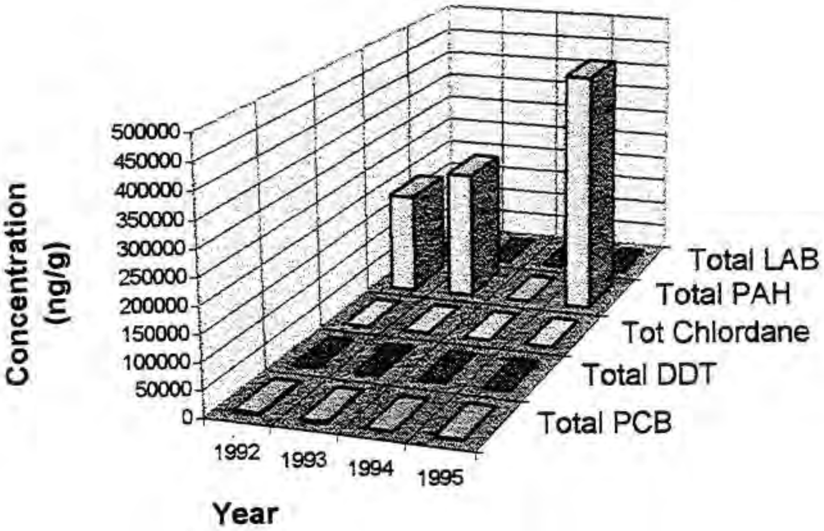


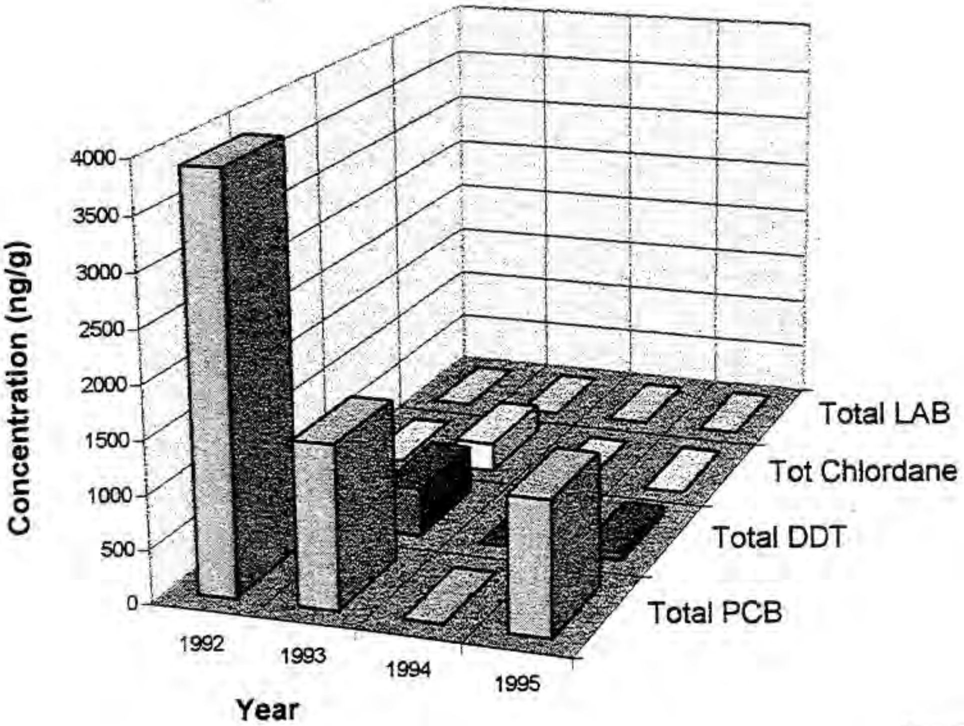
Temporal response of selected TOC-normalized parameters for station NF12



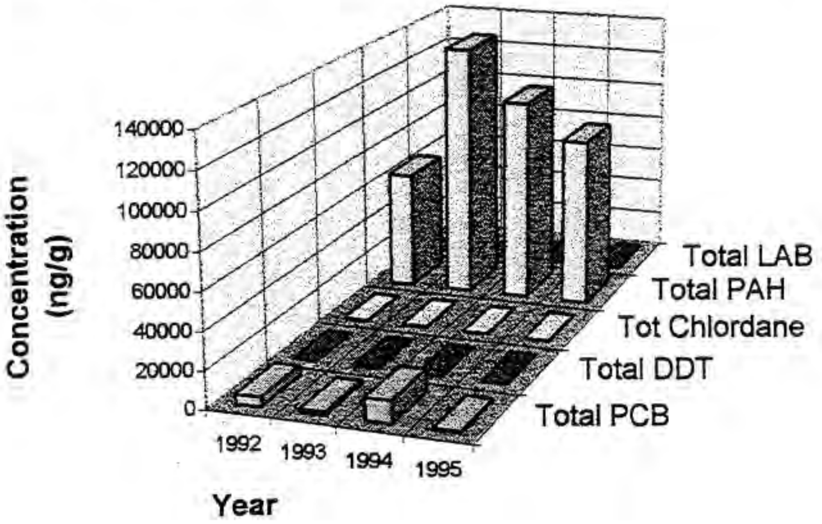


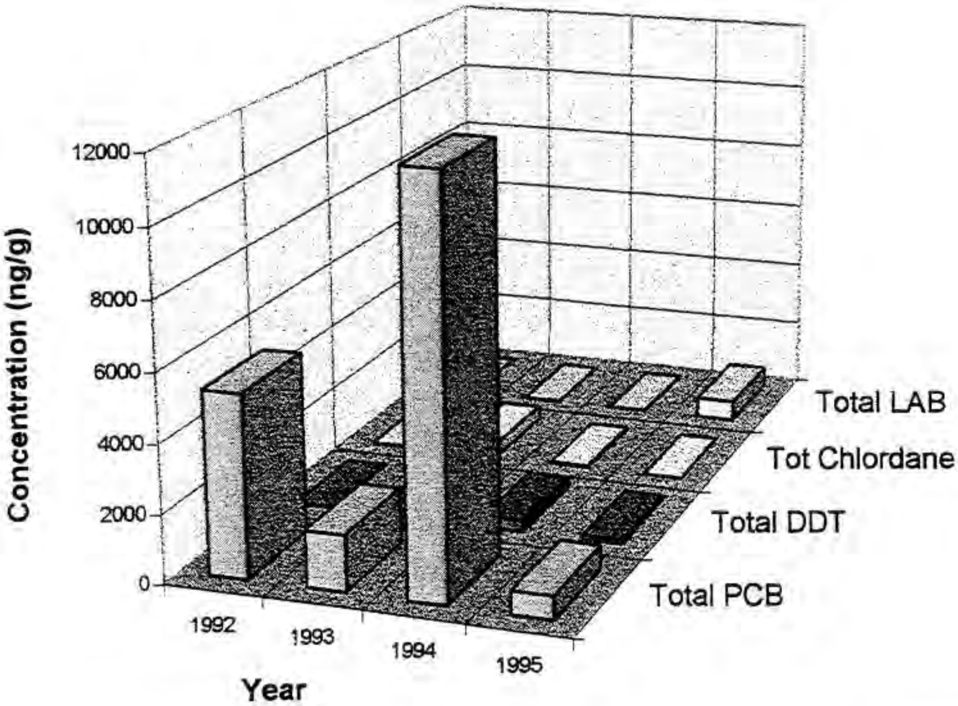
Temporal response of selected TOC-normalized parameters for station FF1



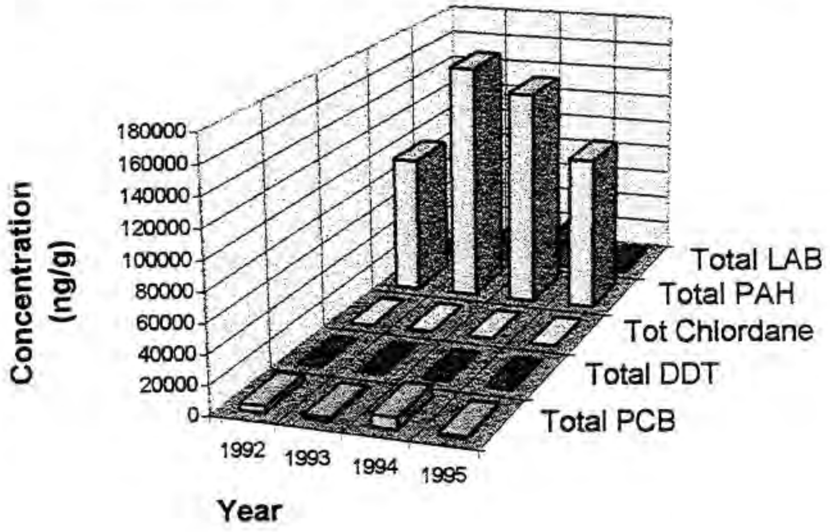


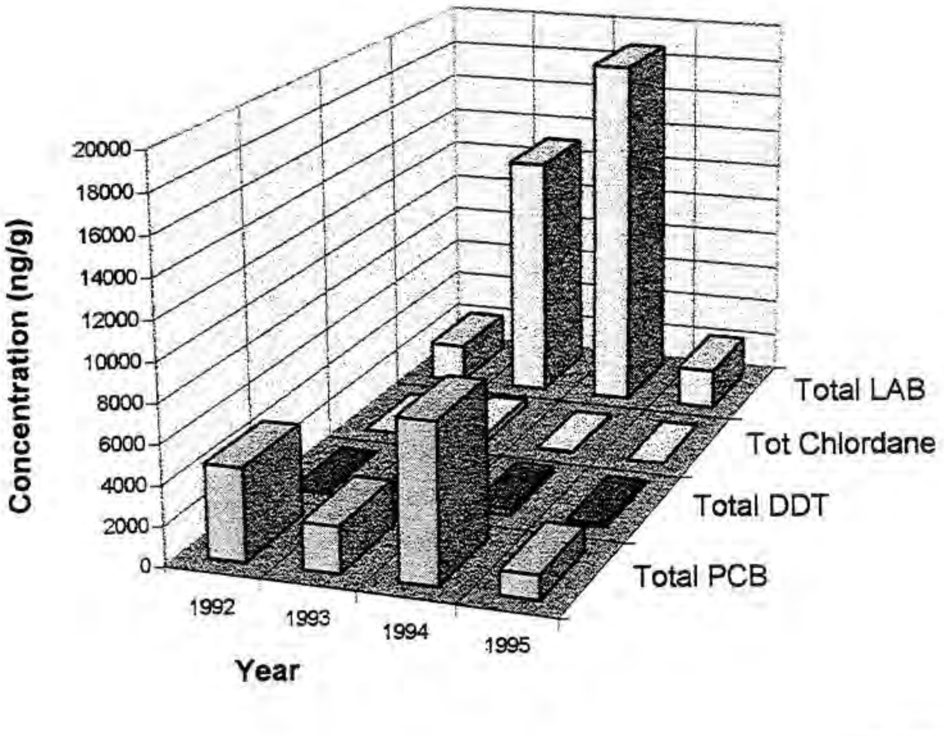
Temporal response of selected TOC-normalized parameters for station FF5



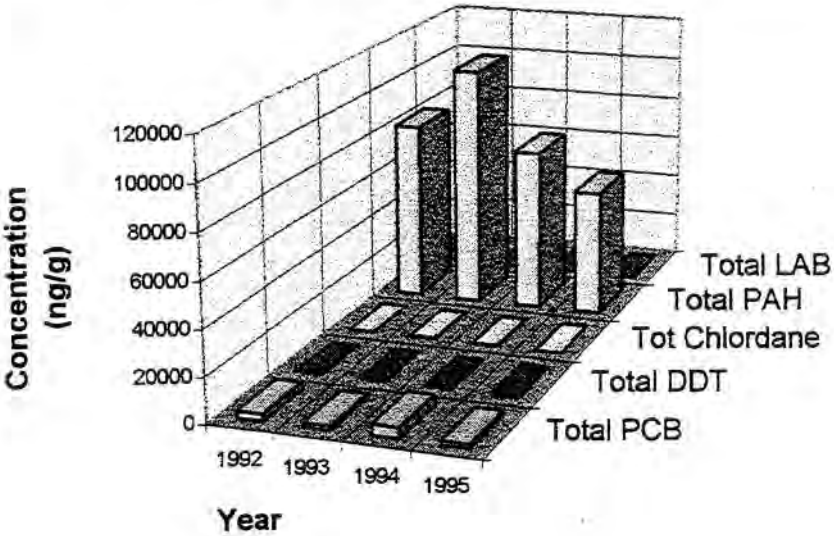


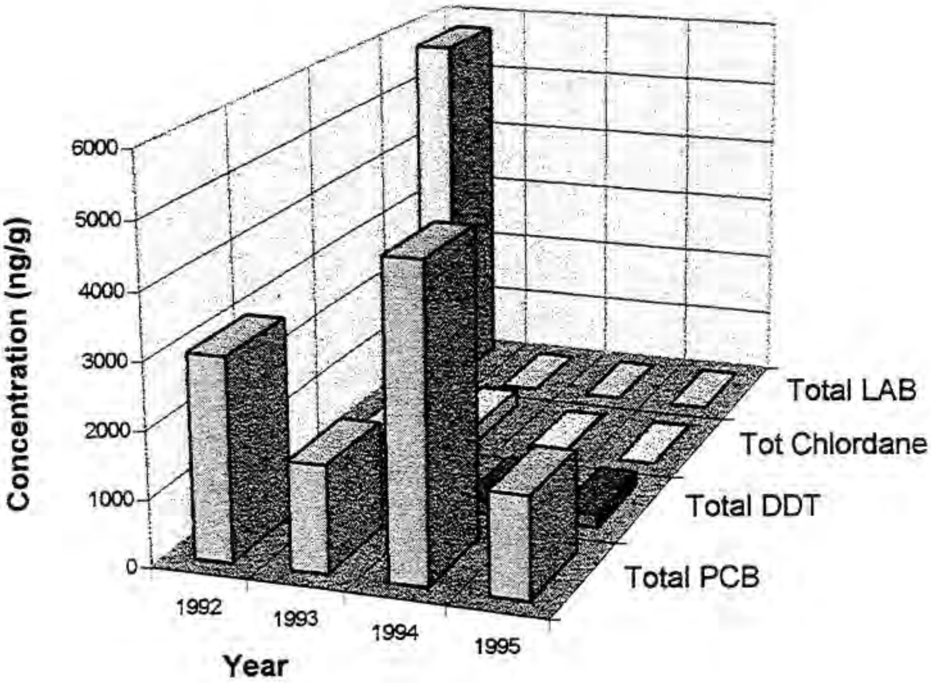
Temporal response of selected TOC-normalized parameters for station FF6



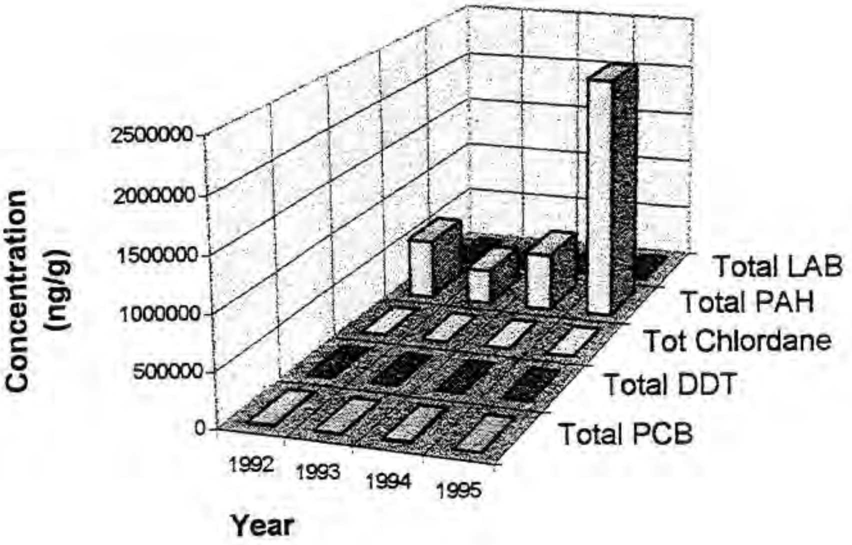


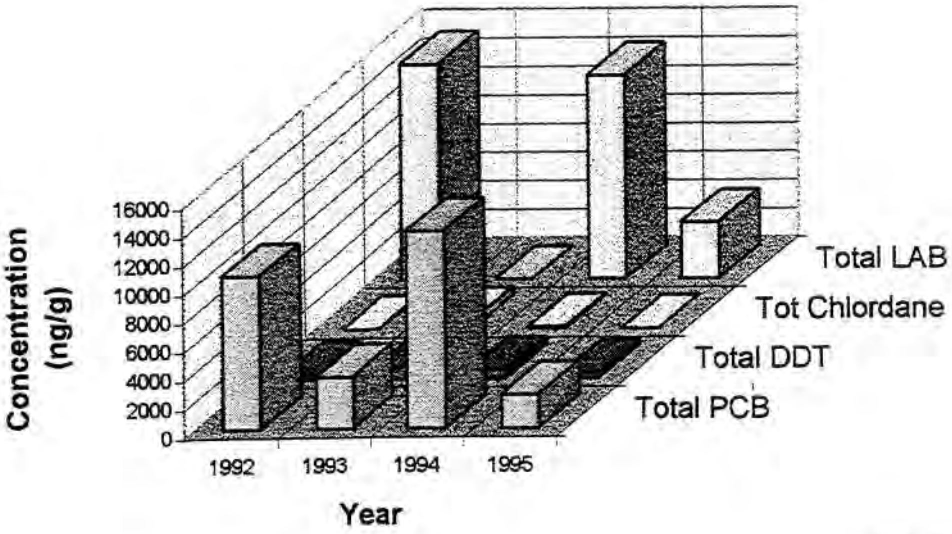
Temporal response of selected TOC-normalized parameters for station FF7



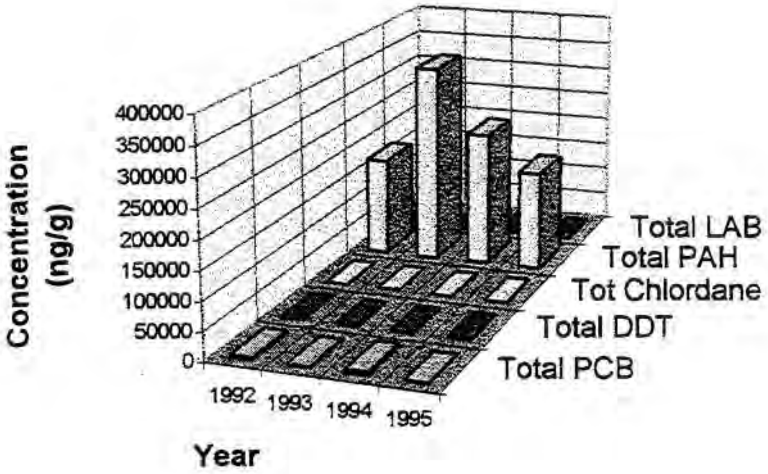


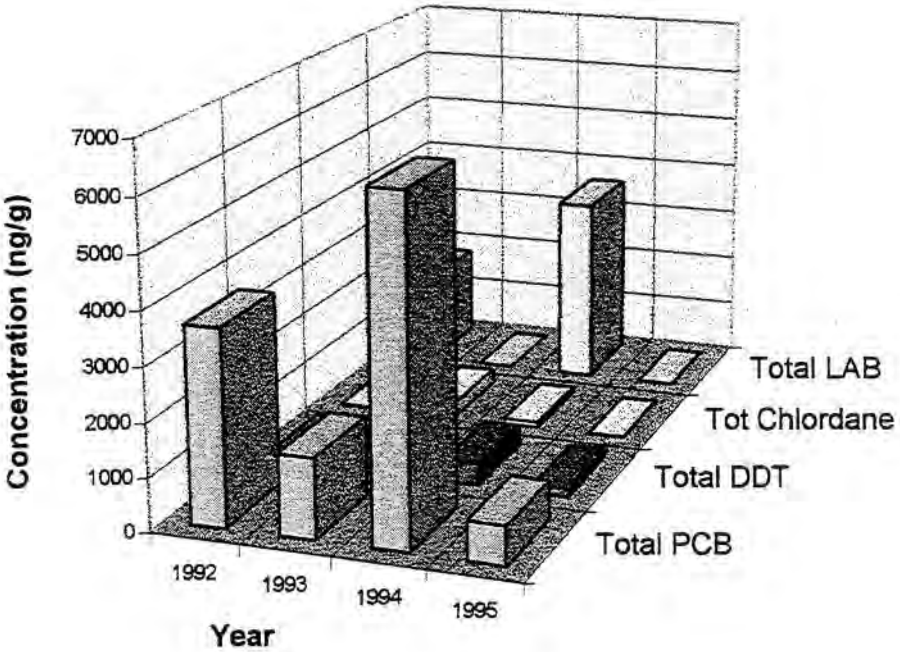
Temporal response of selected TOC-normalized parameters for station FF10



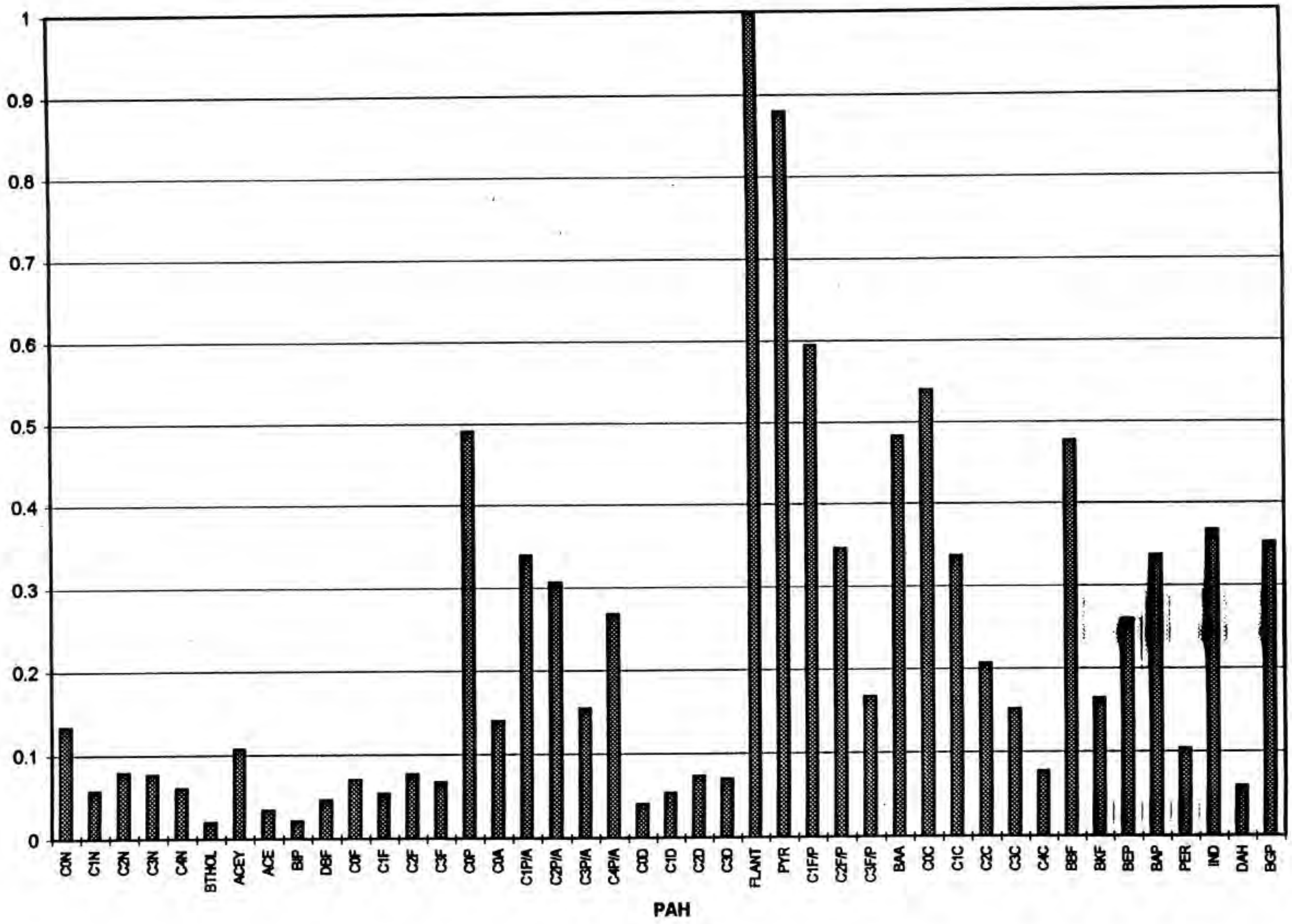


Temporal response of selected TOC-normalized parameters for station FF11

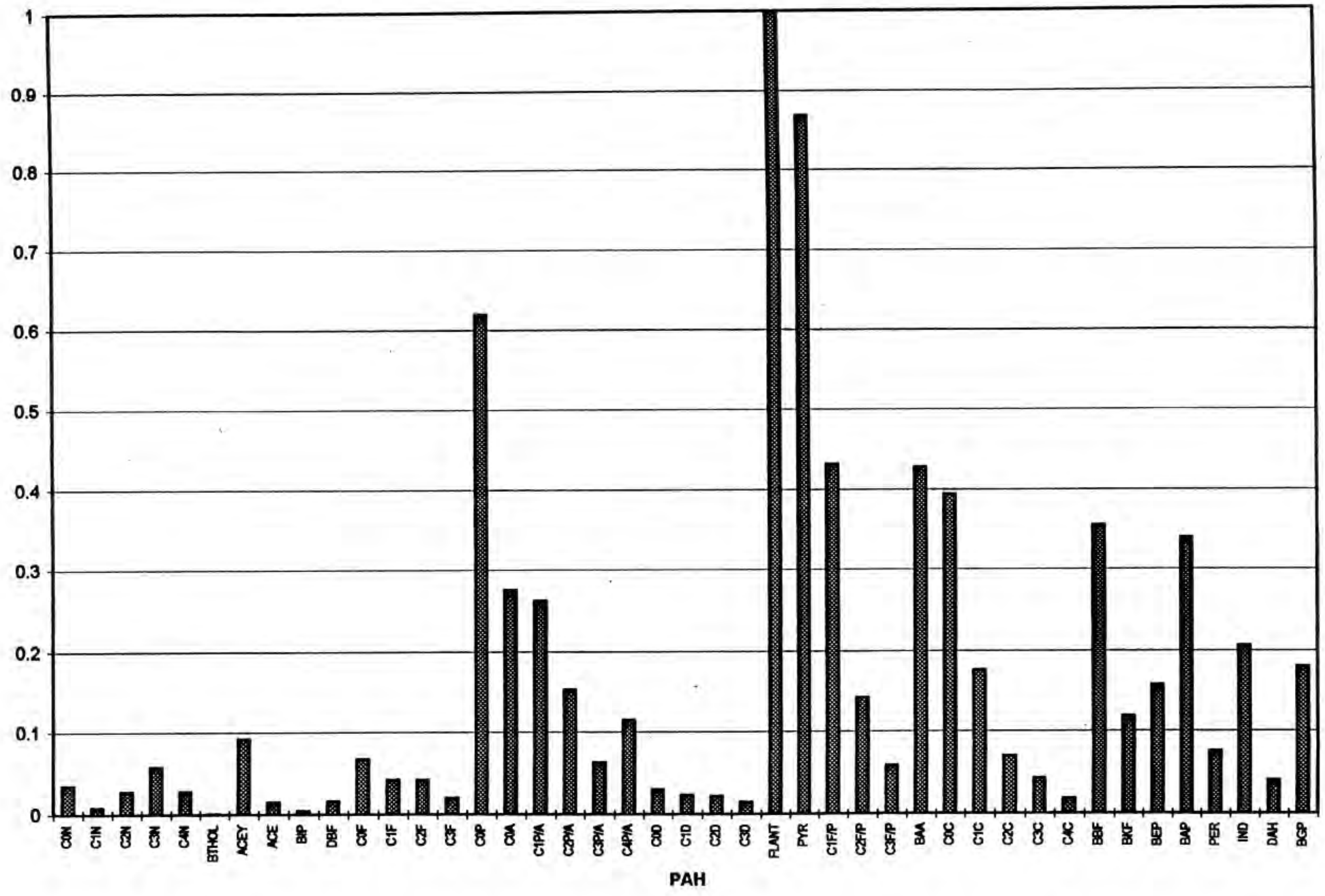




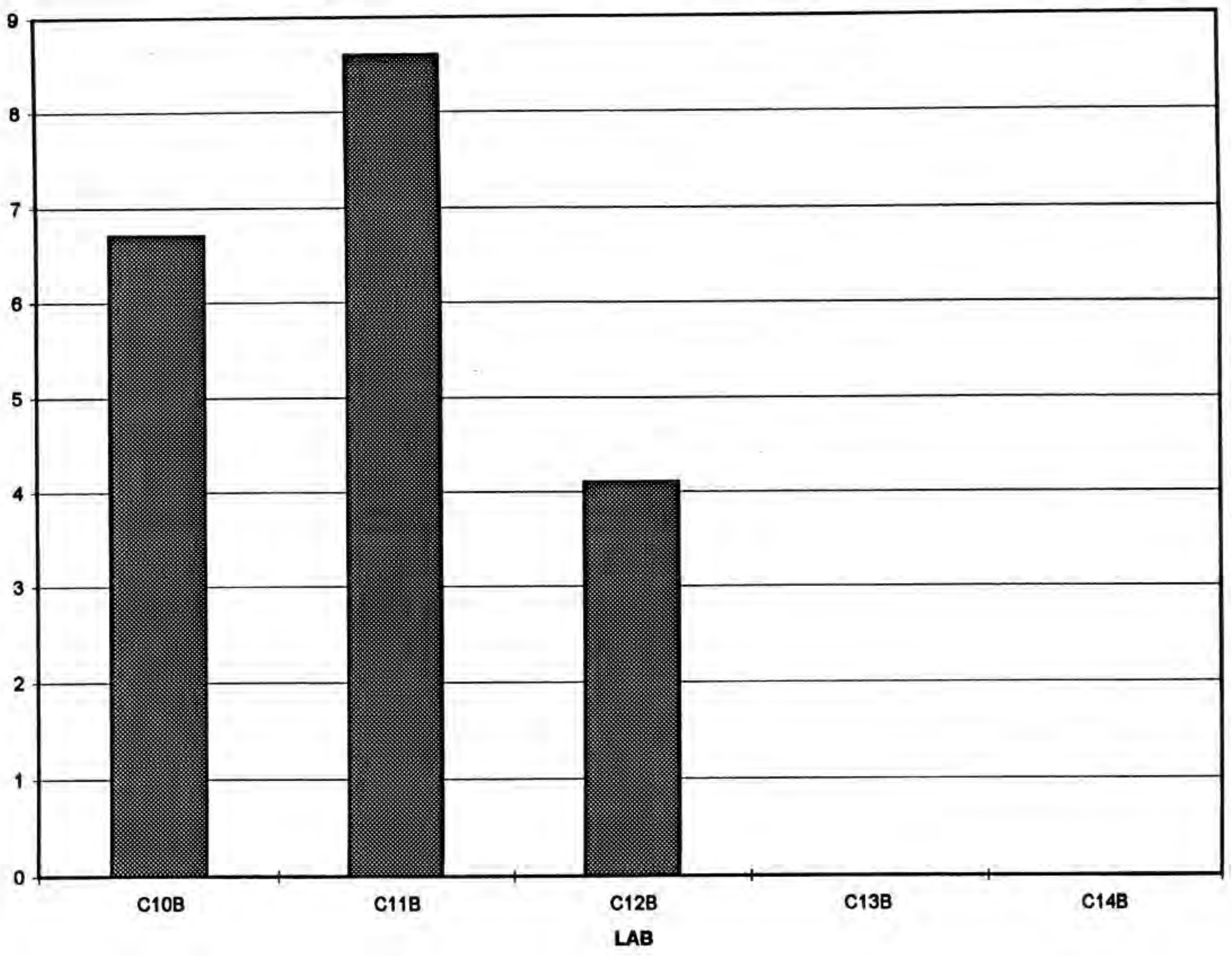
Relative PAH distributions for Station FF6



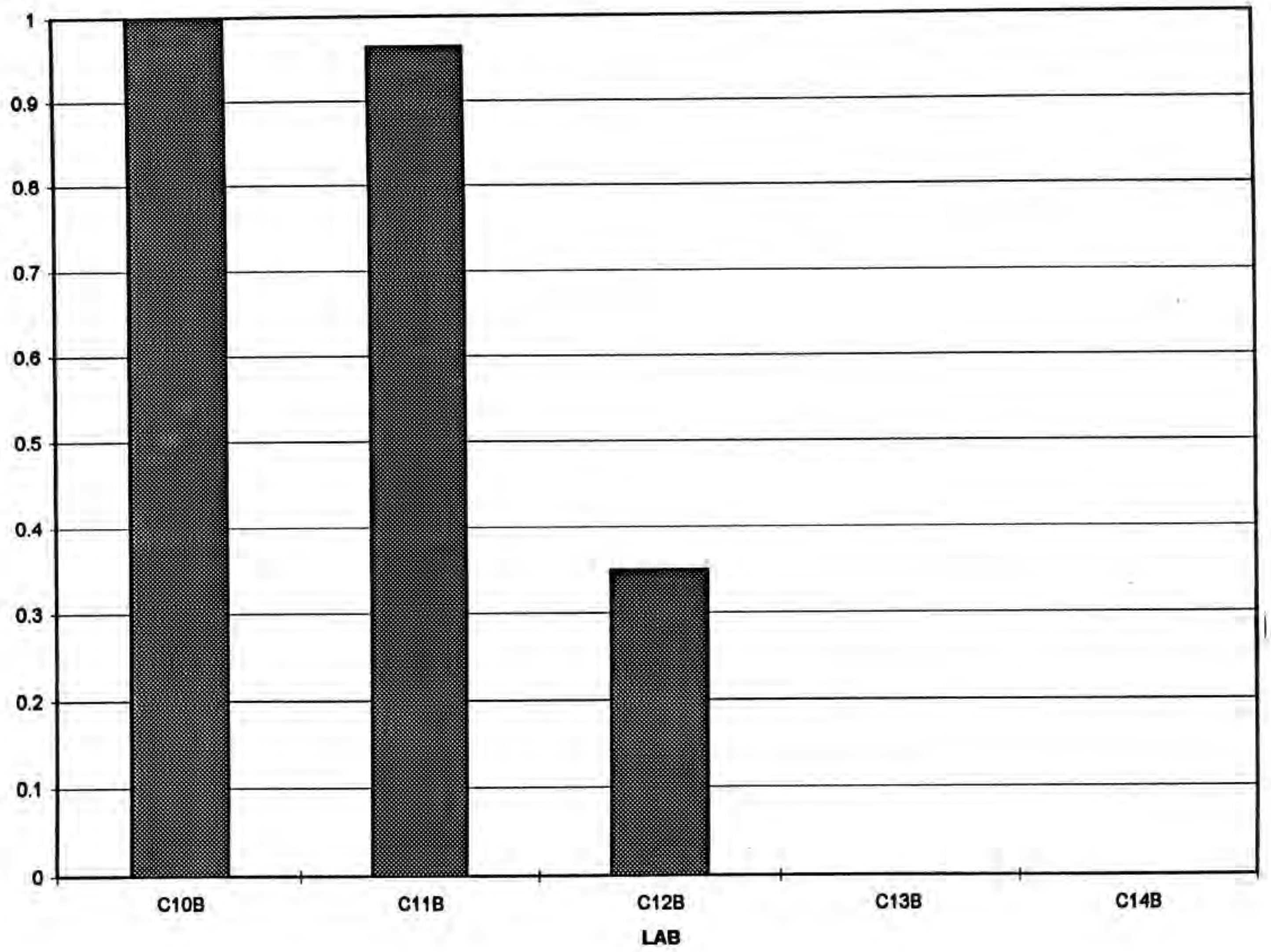
Relative sediment PAH distributions for station FF10 (data is normalized to FLANT).



Relative LAB distributions for Station NF10. (Data is normalized to the compound of highest concentration.)



Relative LAB distributions for Station FF6. (Data is normalized to the compound of highest concentration.)



APPENDIX C-6

Jim Blake and Brigitte Hilbig
ENSR

DOMINANT SPECIES IN THE NEARFIELD

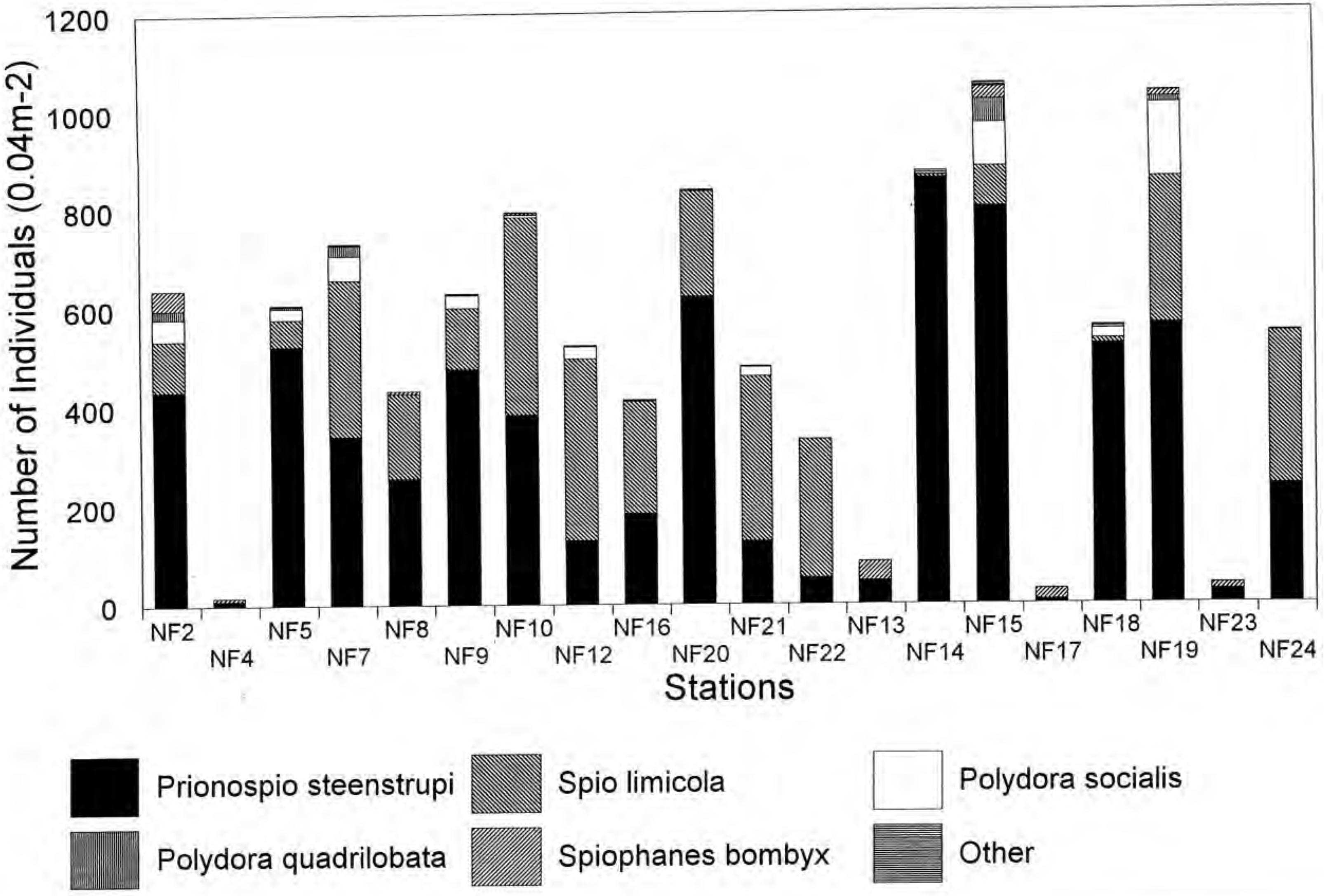
- Most common dominant species in the Nearfield: *Prionospio steenstrupi* (among top ten at 17 stations), *Spio limicola* (14 stations), and *Mediomastus californiensis* (15 stations).

- Peak densities of *P. steenstrupi* and *S. limicola* roughly 20,000 individuals per m^2, in center of Nearfield area, Stations NF10, NF14, NF15, NF19, and NF20, near Nearfield/Midfield boundary.

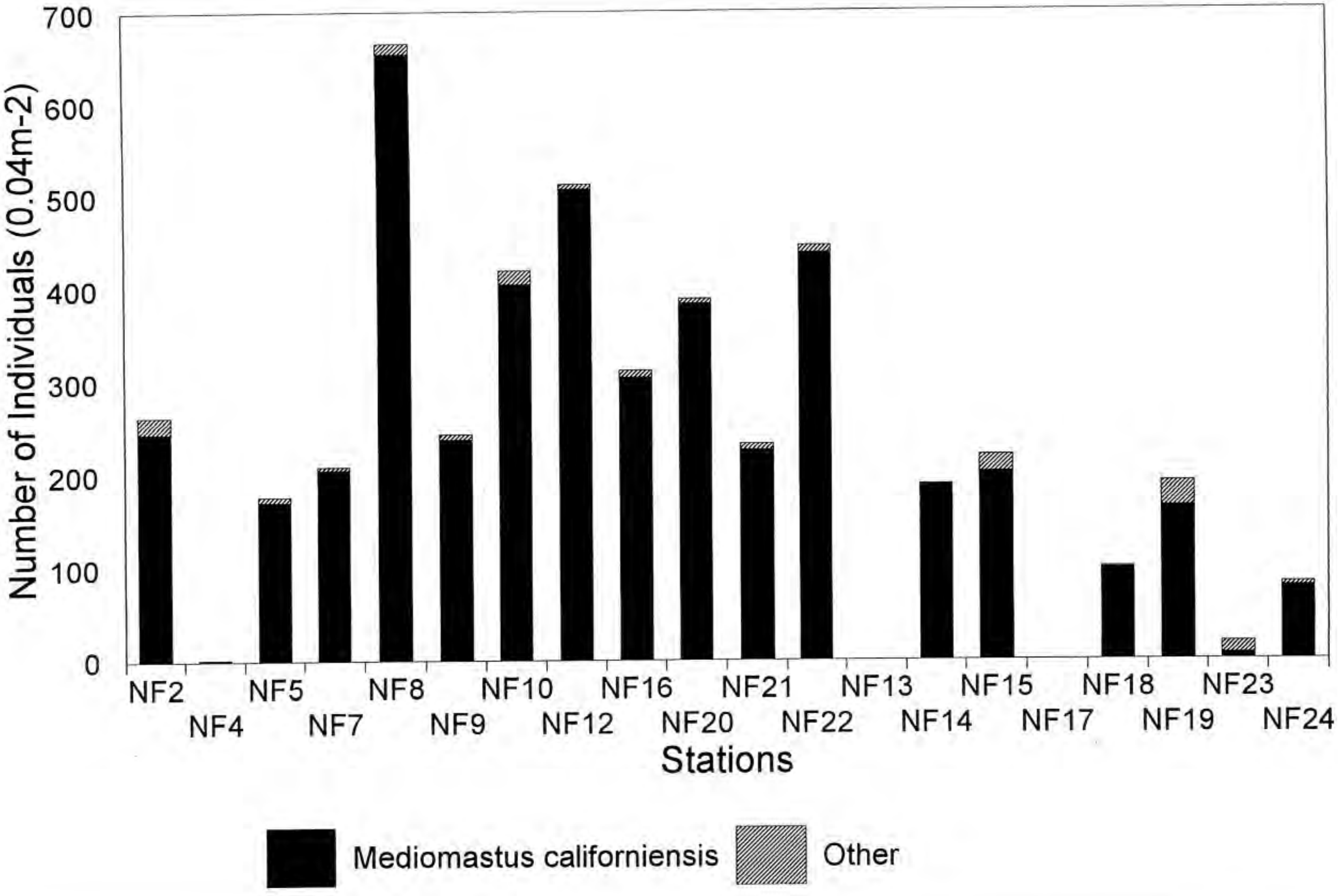
- Peak densities of *M. californiensis* approximately 16,000 individuals per m^2, at Stations NF8, NF10, and NF12, all Midfield.

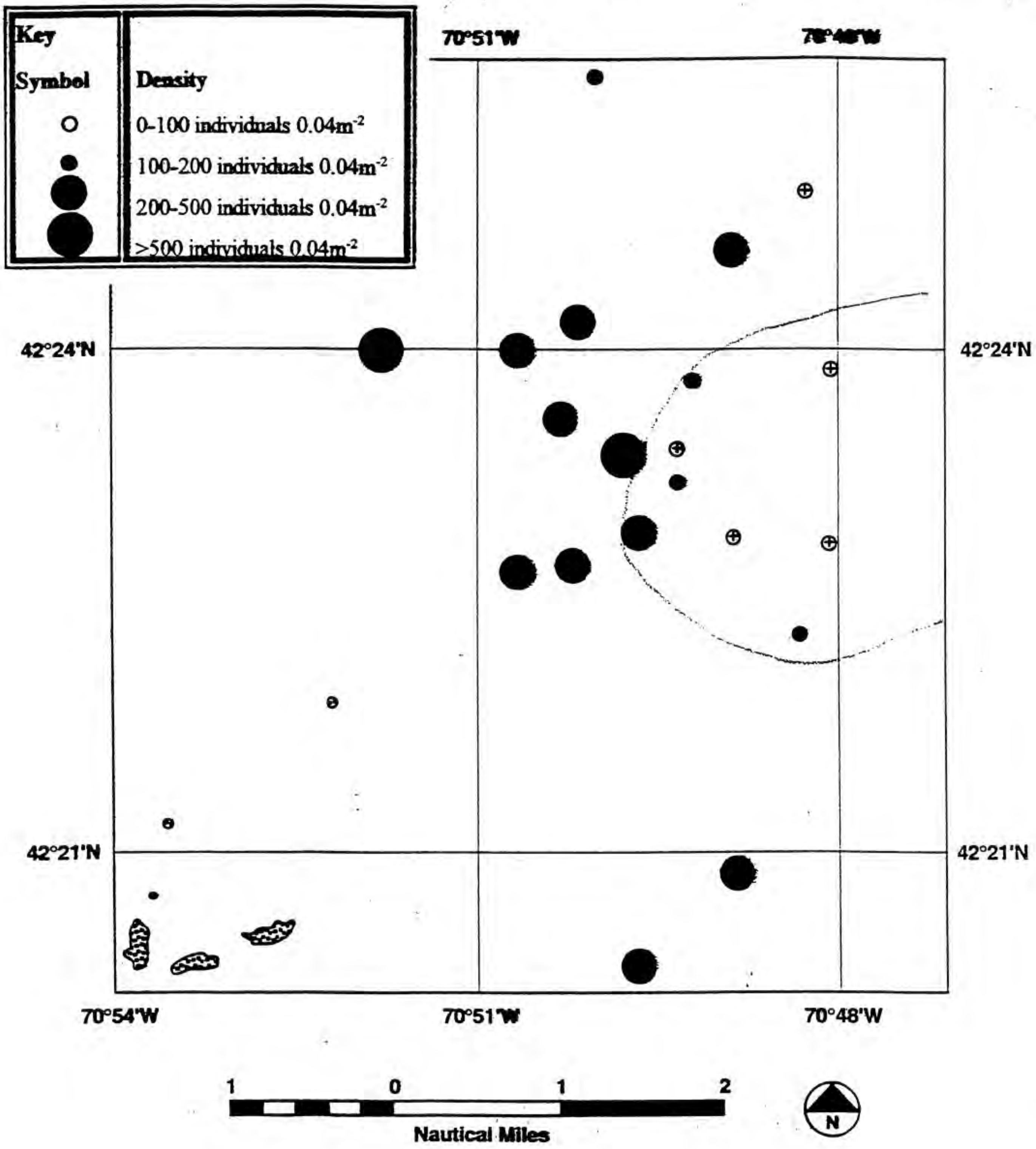
MWRA HOM 1995 - Nearfield Softbottom

Spionid densities



MWRA HOM 1995 - Nearfield Softbottom
Capitellid densities





Key
Symbol
Density
○ 0-100 individuals 0.04m-2
● 100-200 individuals 0.04m-2
● 200-500 individuals 0.04m-2
● >500 individuals 0.04m-2
70°51'W
70°48'W
42°24'N
42°24'N
42°21'N
42°21'N
70°54'W
70°51'W
70°48'W
1
0
1
2
Nautical Miles
N

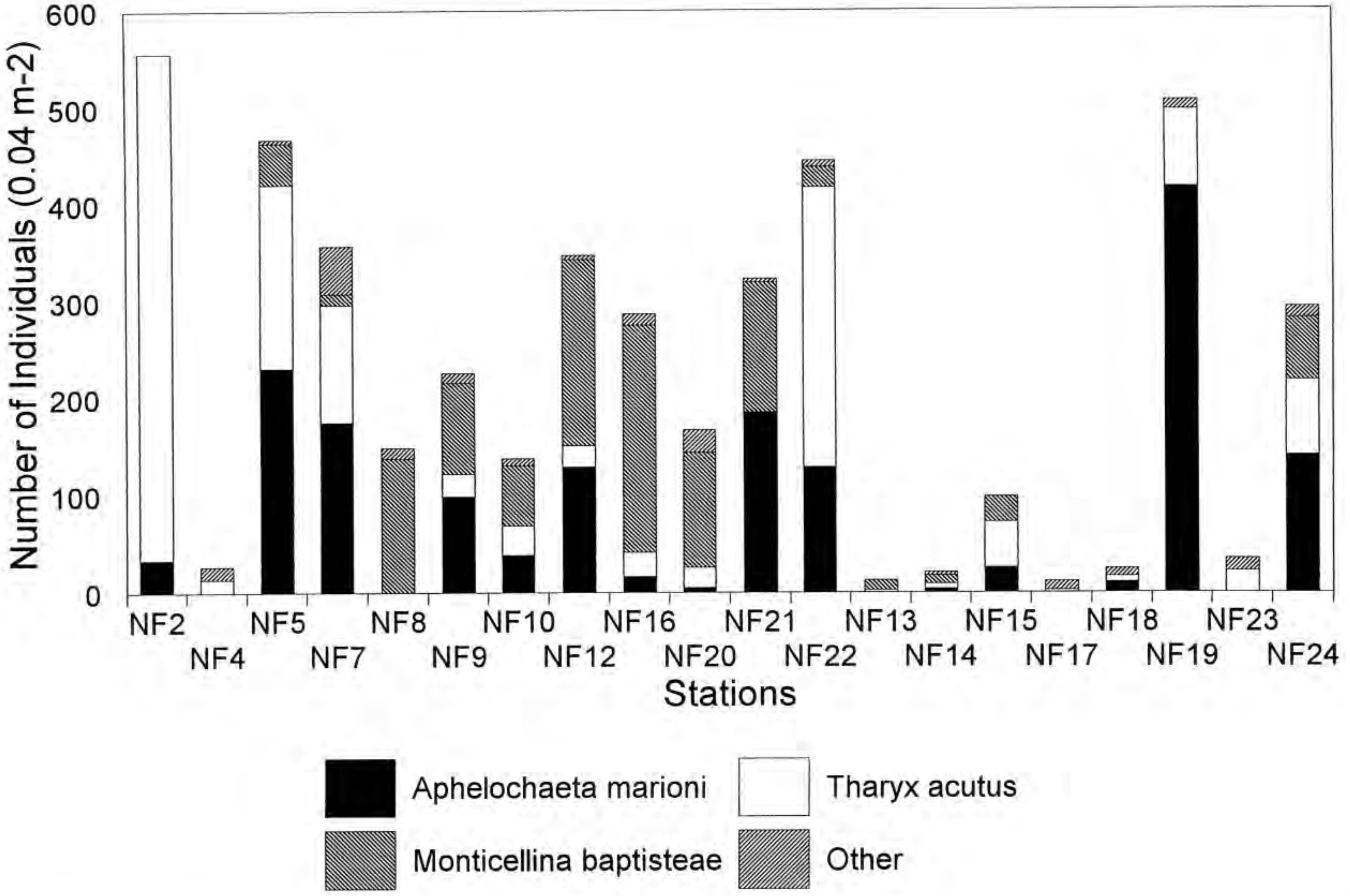
DOMINANT SPECIES IN THE NEARFIELD

- Other species commonly among top ten species: *Tharyx acutus*, *Aphelochaeta marioni*, and *Monticellina baptisteae* (Cirratulidae). Peak densities of *T. acutus* and *A. marioni* together about 5,000 to 10,000 individuals per m^2, at stations NF2, NF5, and NF7 (Midfield).

- Dominant species more characteristic of sandy sediments: Syllidae. *Exogone hebes* and *E. verugera* combined with peak densities of about 7,000 to 14,000 individuals per m^2, at stations NF13, NF14, and NF23 (Nearfield).

- Other sand-dwelling dominants: Enchytraeidae sp. 1 (Oligochaeta, stations NF4 and NF23), *Polygordius* sp. A ("Archiannelida", station NF17), and *Corophium crassicorne* (Amphipoda, stations NF4, NF13, NF17, and NF23).

- Paraonidae very abundant at stations close to Boston Harbor (NF2, NF8), densities of *Aricidea catherinae* 14,000 to 27,000 individuals per m^2, similar to neighboring Harbor stations T6 and T7.

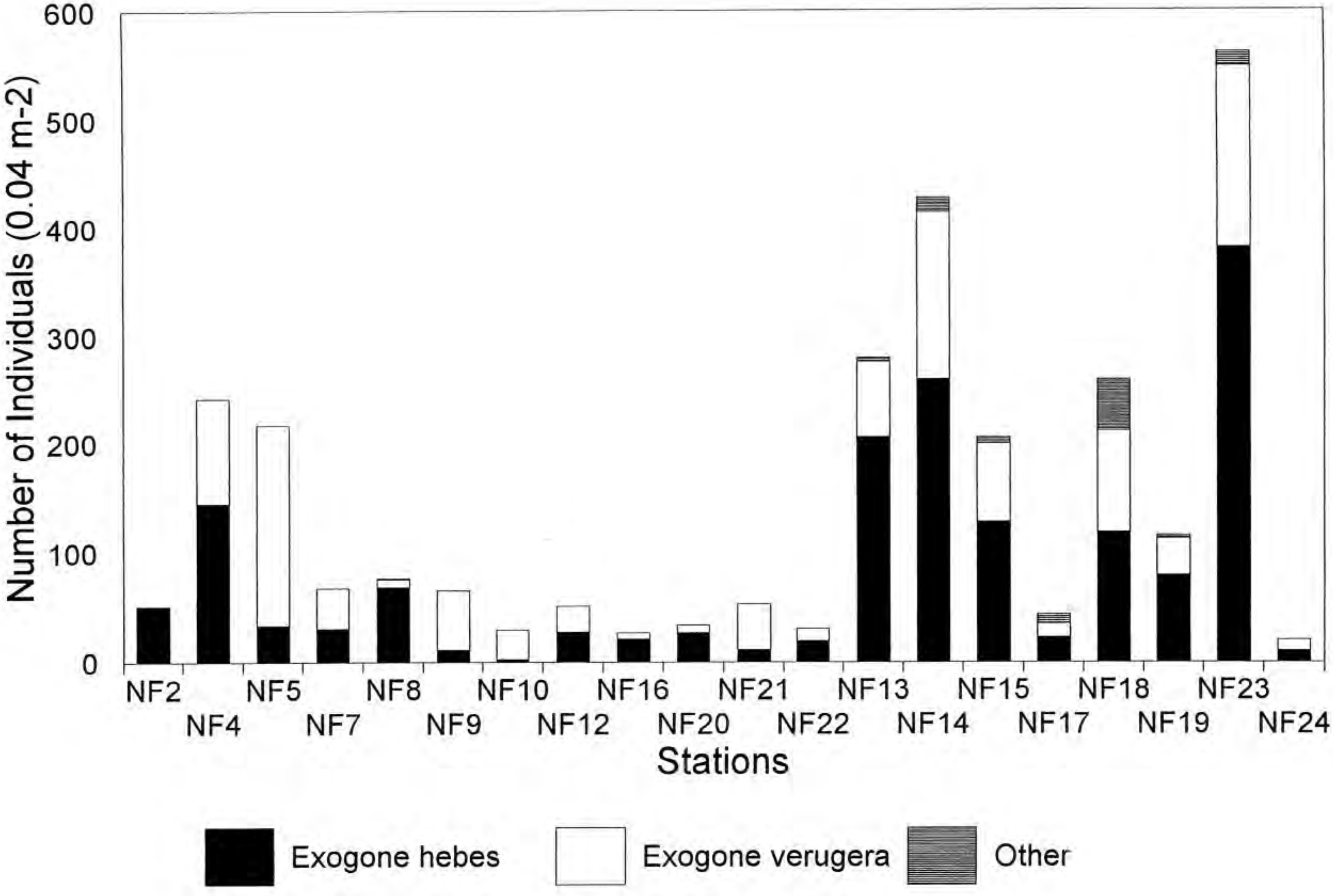


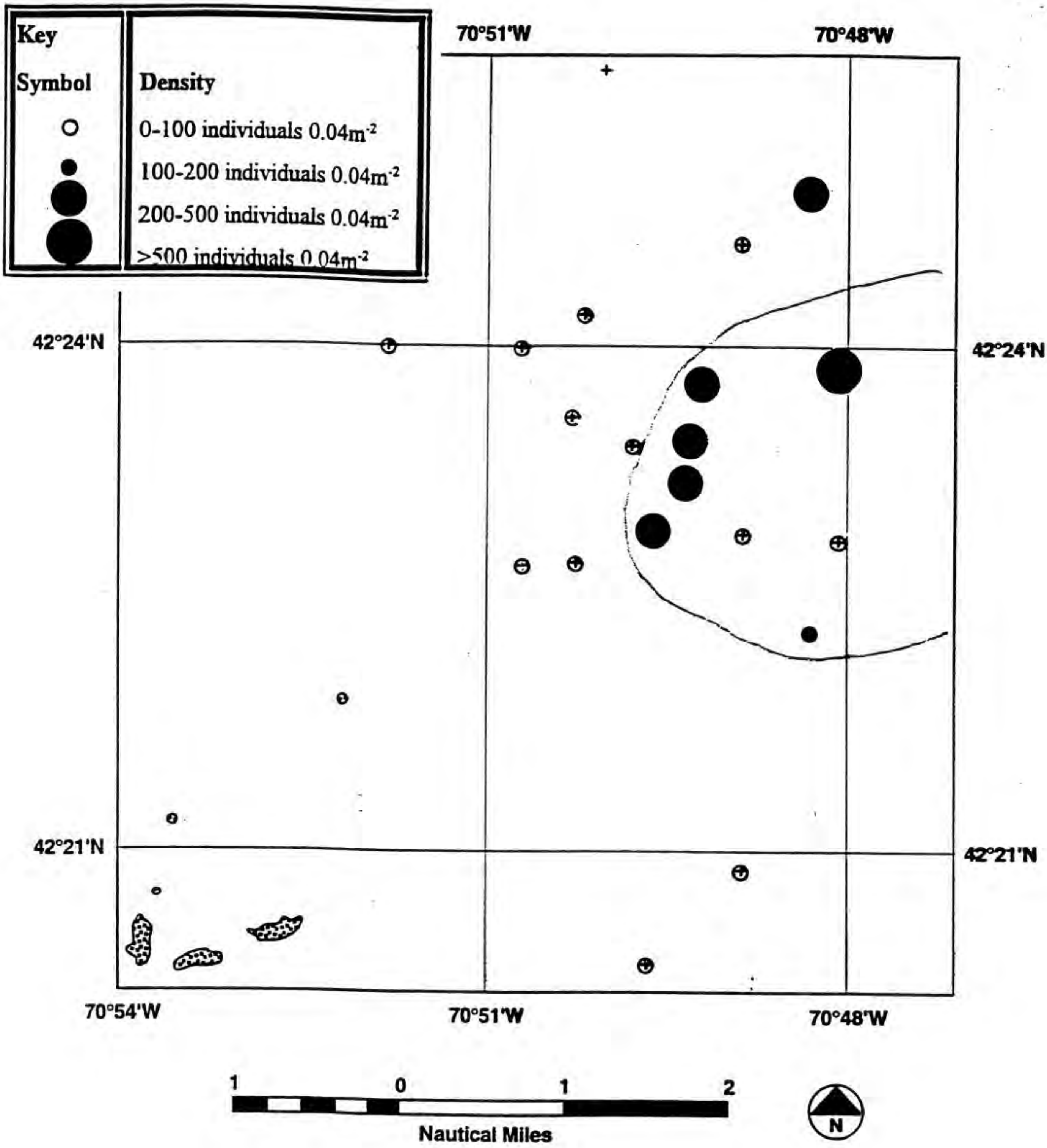
MWRA HOM 1995 - Nearfield Softbottom

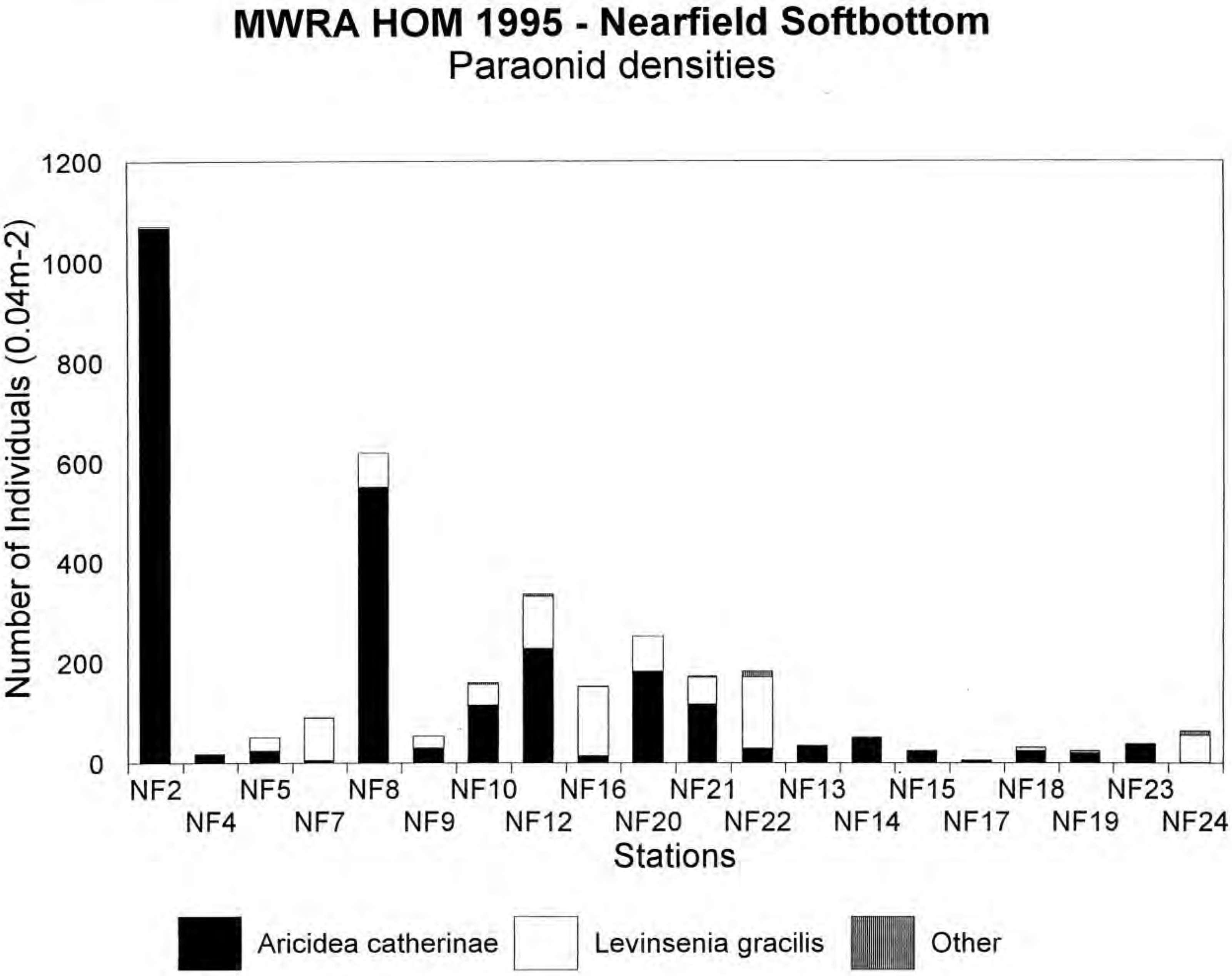
Cirratulid densities

MWRA HOM 1995 - Nearfield Softbottom

Syllid densities




Key
Symbol
Density
○ 0-100 individuals $0.04m^{-2}$
● 100-200 individuals $0.04m^{-2}$
● 200-500 individuals $0.04m^{-2}$
● >500 individuals $0.04m^{-2}$
70°51'W
70°48'W
42°24'N
42°24'N
42°21'N
42°21'N
70°54'W
70°51'W
70°48'W
1
0
1
2
Nautical Miles
N



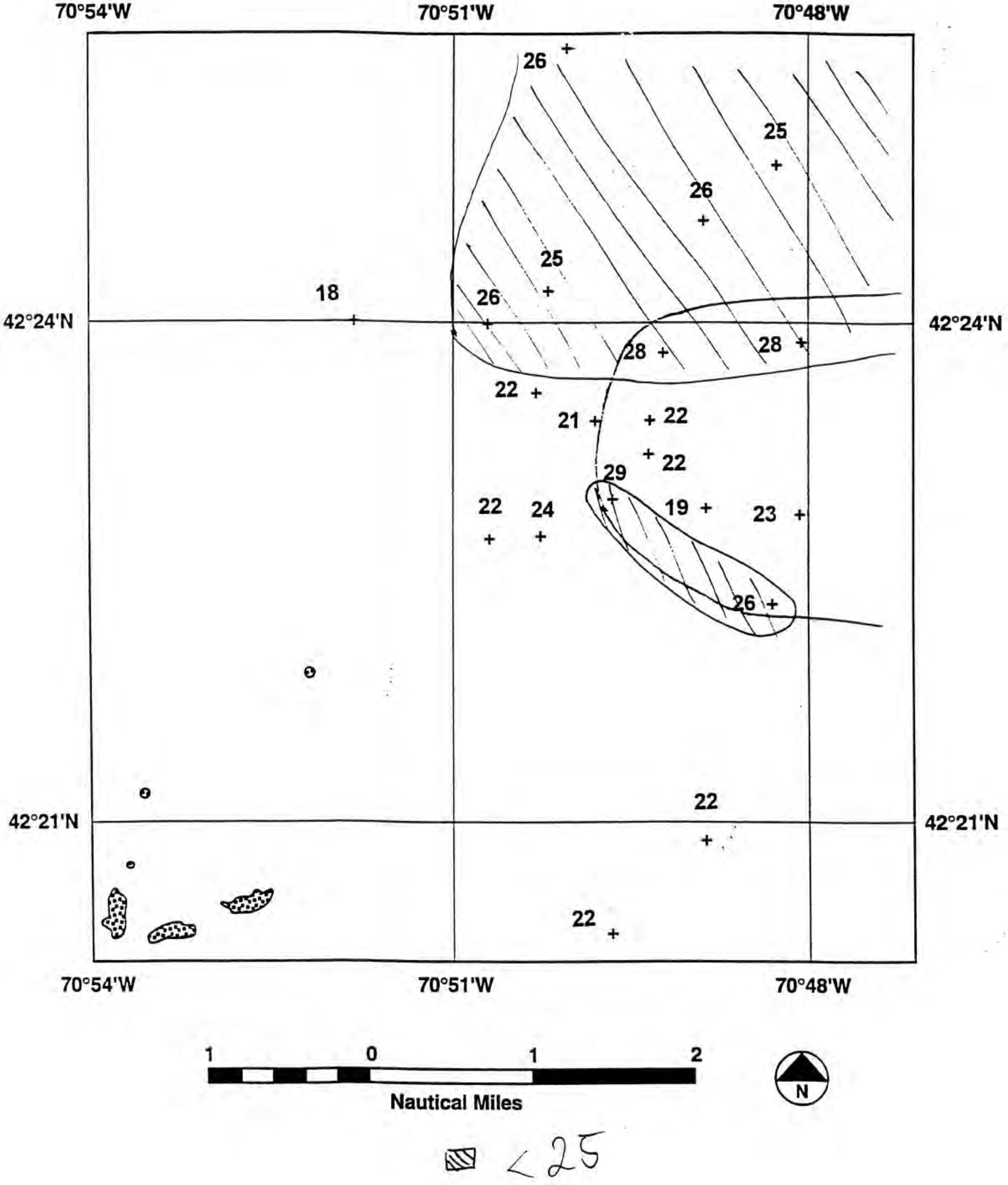
MWRA HOM 1995 - Nearfield Softbottom
Paraonid densities

SPECIES RICHNESS AND DIVERSITY IN THE NEARFIELD

- Number of species per 0.04-m^2 varied between 45 and 85, for most stations between 55 and 75. Lowest number of species generally in sand and very silty muds, highest in mixed sediments.

- Total infaunal density ranged from 900 to 3,500 individuals per 0.04-m^2 grab; slight tendency toward lower densities offshore in more sandy sediments.

- Diversity, expressed as number of species per 100 individuals, ranged from about 18 to 29. Lowest diversity indices found for band of stations crossing Nearfield area from NW to SE. Effect of grain size less obvious, low number of species balanced by low abundances; high sedimentation rates and high TOC concentrations may have an influence.


70°54'W
70°51'W
70°48'W
26
25
26
25
18
26
42°24'N
42°24'N
28
28
22
21
22
22
29
22
24
19
23
26
22
42°21'N
42°21'N
22
70°54'W
70°51'W
70°48'W
1
0
1
2
Nautical Miles
N
▨ < 25

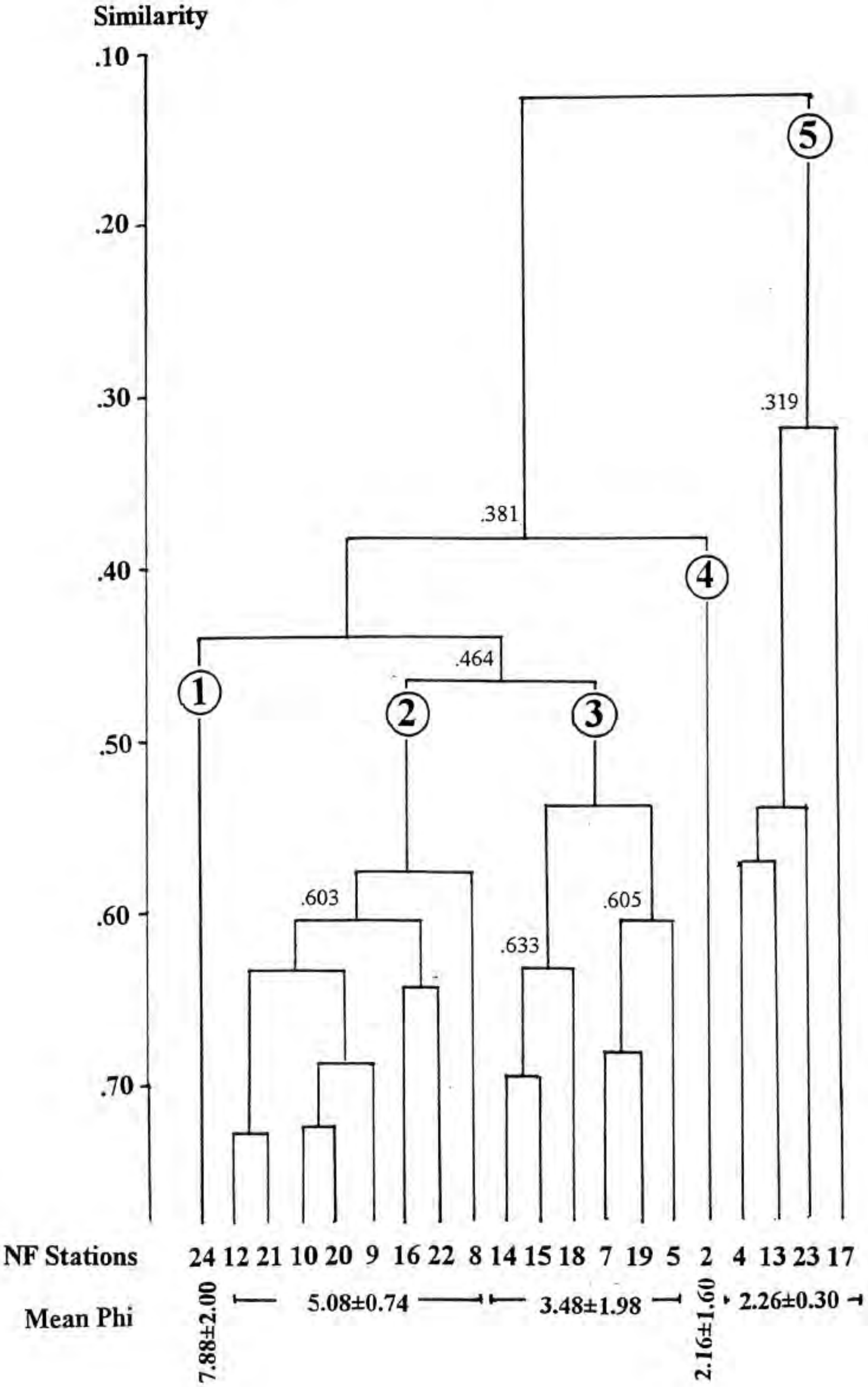
COMMUNITY ANALYSIS, NEARFIELD STATIONS

- Similarity among the Nearfield stations was measured with Bray-Curtis and Gallagher's CNESS.

- With both techniques, stations group mostly by sediment grain size. Differences between the clusters reflect sensitivity of clustering techniques to non-dominant species. The sandy stations NF4, NF13, NF17, and NF23 are clustering together in both dendrograms.

- Cluster 2 of Bray-Curtis dendrogram includes stations dominated by *Mediomastus californiensis* (mean phi 5.08±0.74), whereas cluster 3 includes stations dominated by *Prionospio steenstrupi* and *Spio limicola* (mean phi 3.48±1.98). Cluster 5 contains the sandy stations (see above) dominated by *Exogone hebes*, *Corophium crassicorne*, and Enchytraeidae sp. 1.

- Midfield stations group in cluster 2, parts of clusters 3 and 5, and cluster 4 (single station).


Similarity
.10
.20
.30
.40
.50
.60
.70
⑤
.319
.381
④
.464
①
②
③
.603
.633
.605
NF Stations
24 12 21 10 20 9 16 22 8 14 15 18 7 19 5 2 4 13 23 17
Mean Phi
7.88±2.00
5.08±0.74
3.48±1.98
2.16±1.60
2.26±0.30

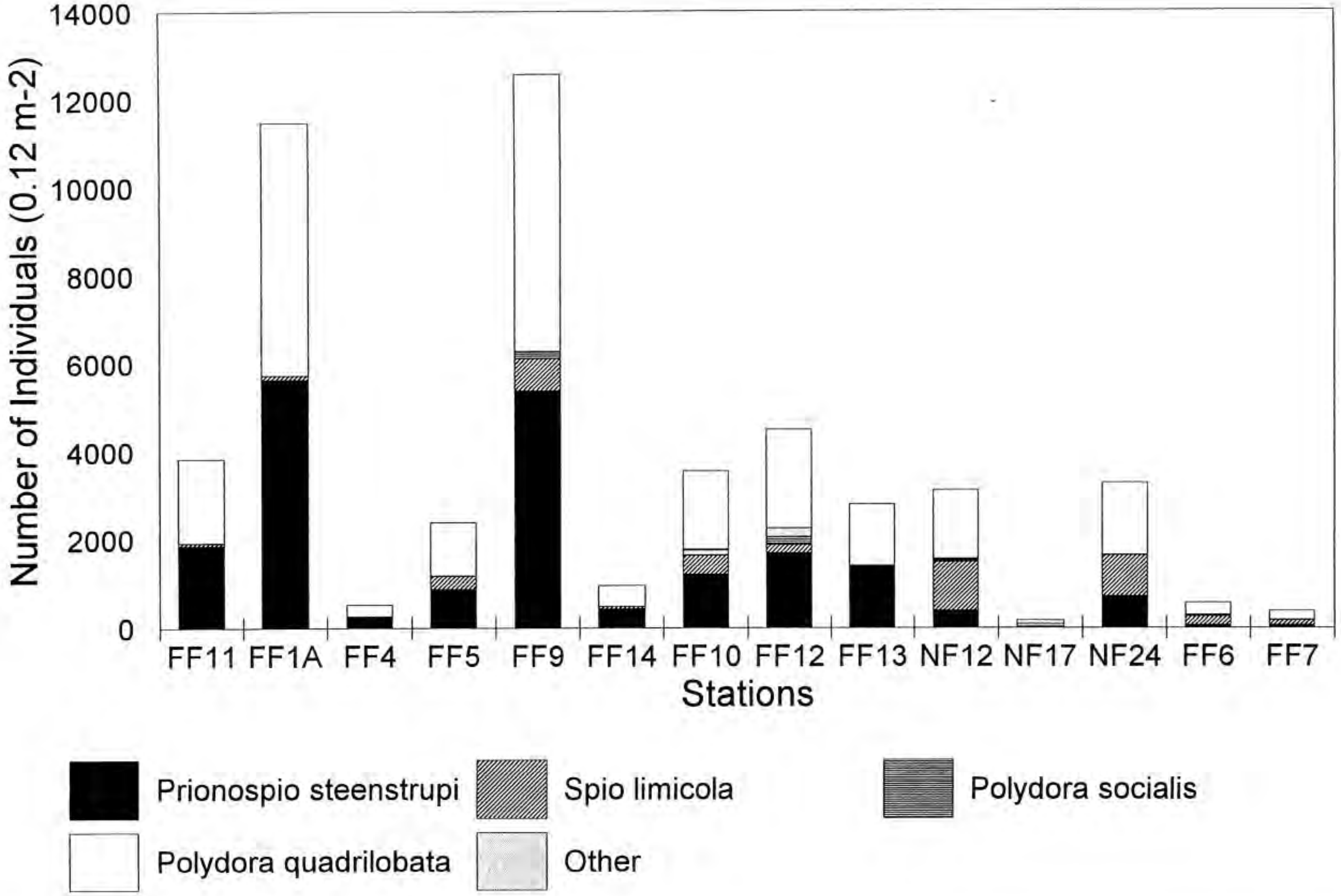
DOMINANT SPECIES IN THE FARFIELD

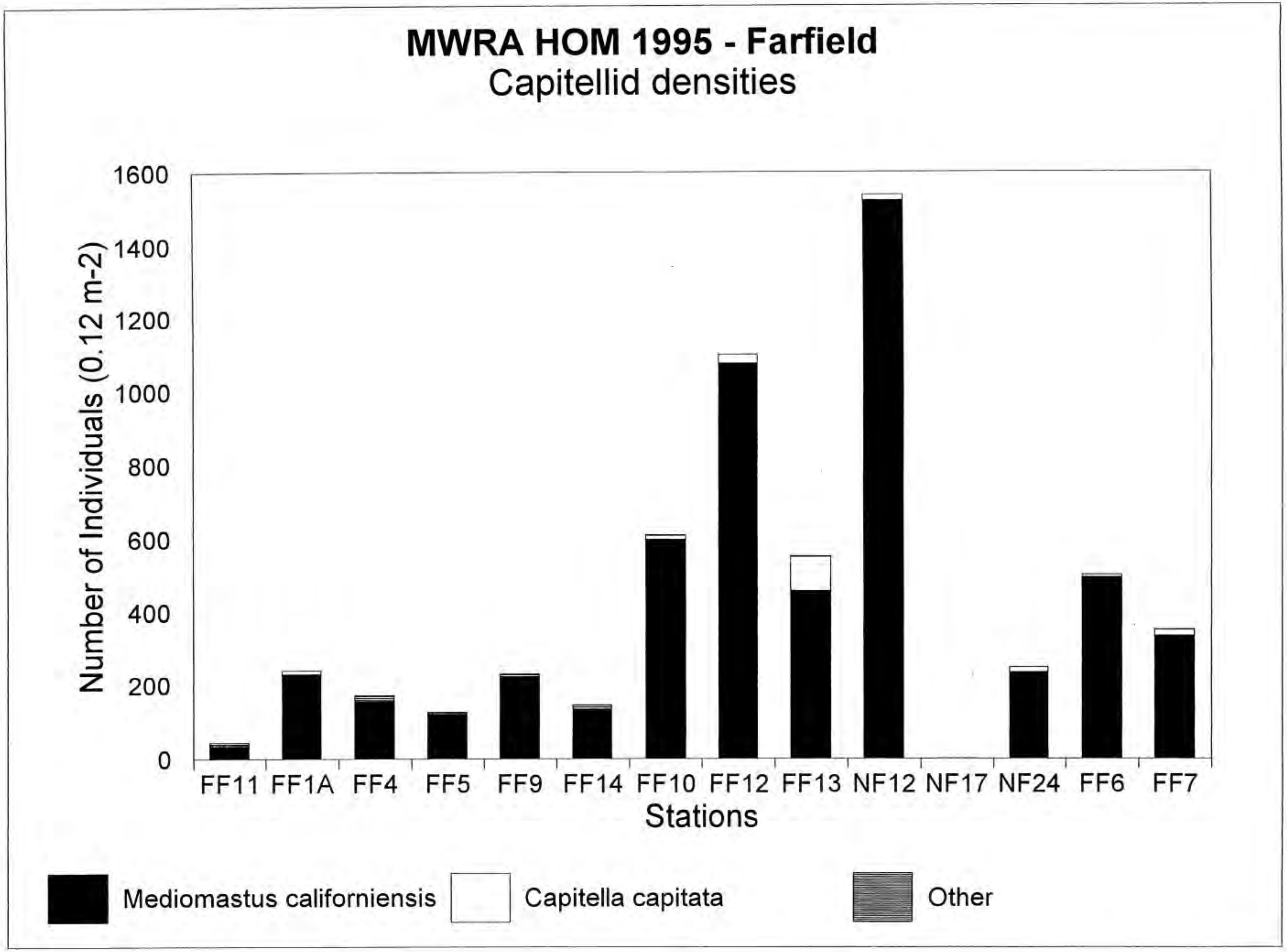
- Most common dominant species in the Farfield: same as in Nearfield; *Mediomastus californiensis* present among dominants at all stations, usually ranking second or third. *Prionospio steenstrupi* top dominant throughout Massachusetts Bay, less abundant in Cape Cod Bay (stations FF6 and FF7), *Spio limicola* among dominants at 8 stations.

- Peak densities of *P. steenstrupi* and *S. limicola* roughly 50,000 individuals per m^2, off Gloucester and in central Massachusetts Bay (stations FF1A and FF9). Also high densities of *Polydora quadrilobata.* Densities at FF10 and FF12 similar to other Midfield stations.

- Peak densities of *M. californiensis* approximately 9,000 to 12,000 individuals per m^2, at Midfield stations; densities about half as high at Cape Cod Bay stations.

MWRA HOM 1995 - Farfield
Spionid densities



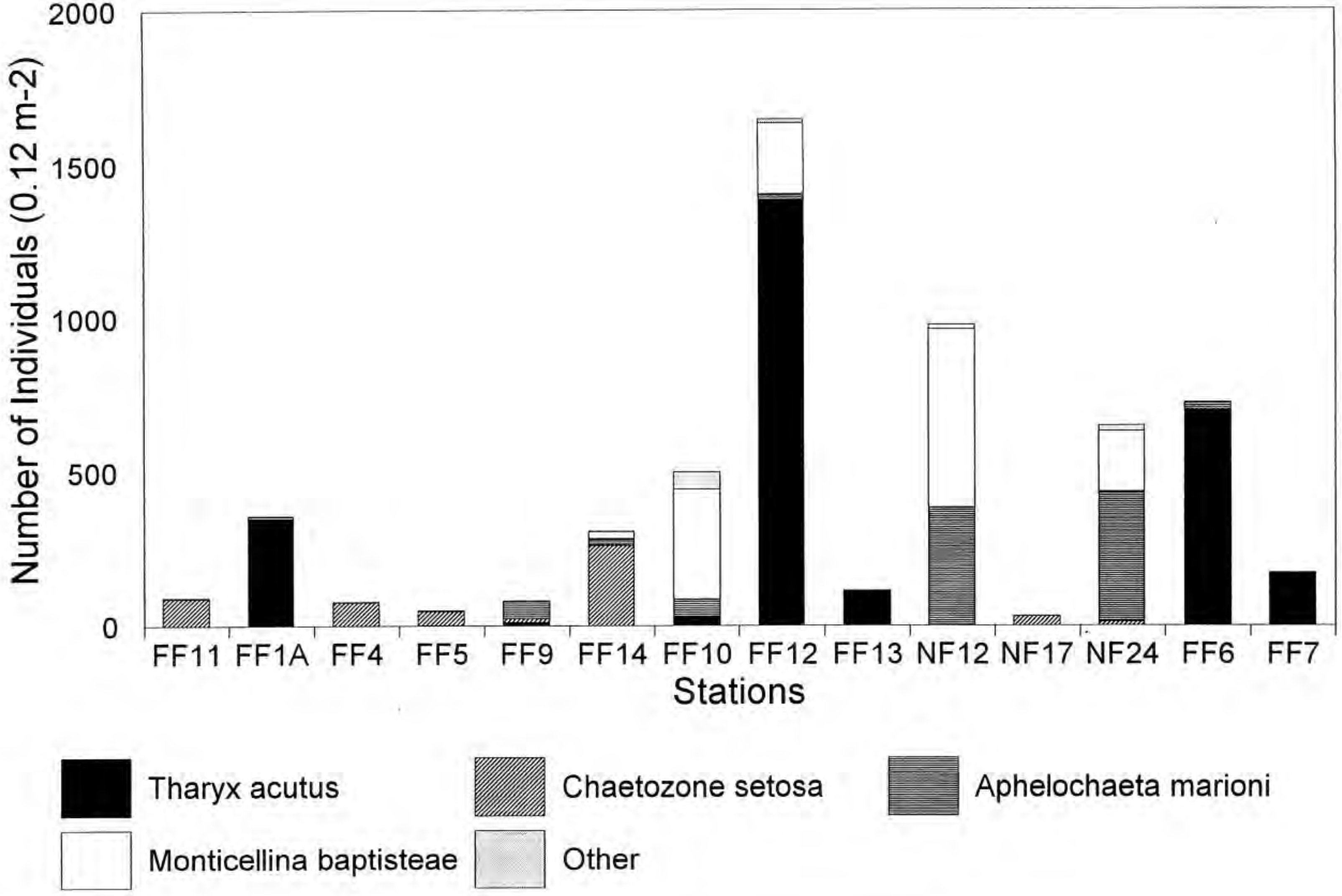

MWRA HOM 1995 - Farfield
Capitellid densities
Number of Individuals (0.12 m-2)
1600
1400
1200
1000
800
600
400
200
0
FF11
FF1A
FF4
FF5
FF9
FF14
FF10
FF12
FF13
NF12
NF17
NF24
FF6
FF7
Stations
Mediomastus californiensis
Capitella capitata
Other

DOMINANT SPECIES IN THE FARFIELD

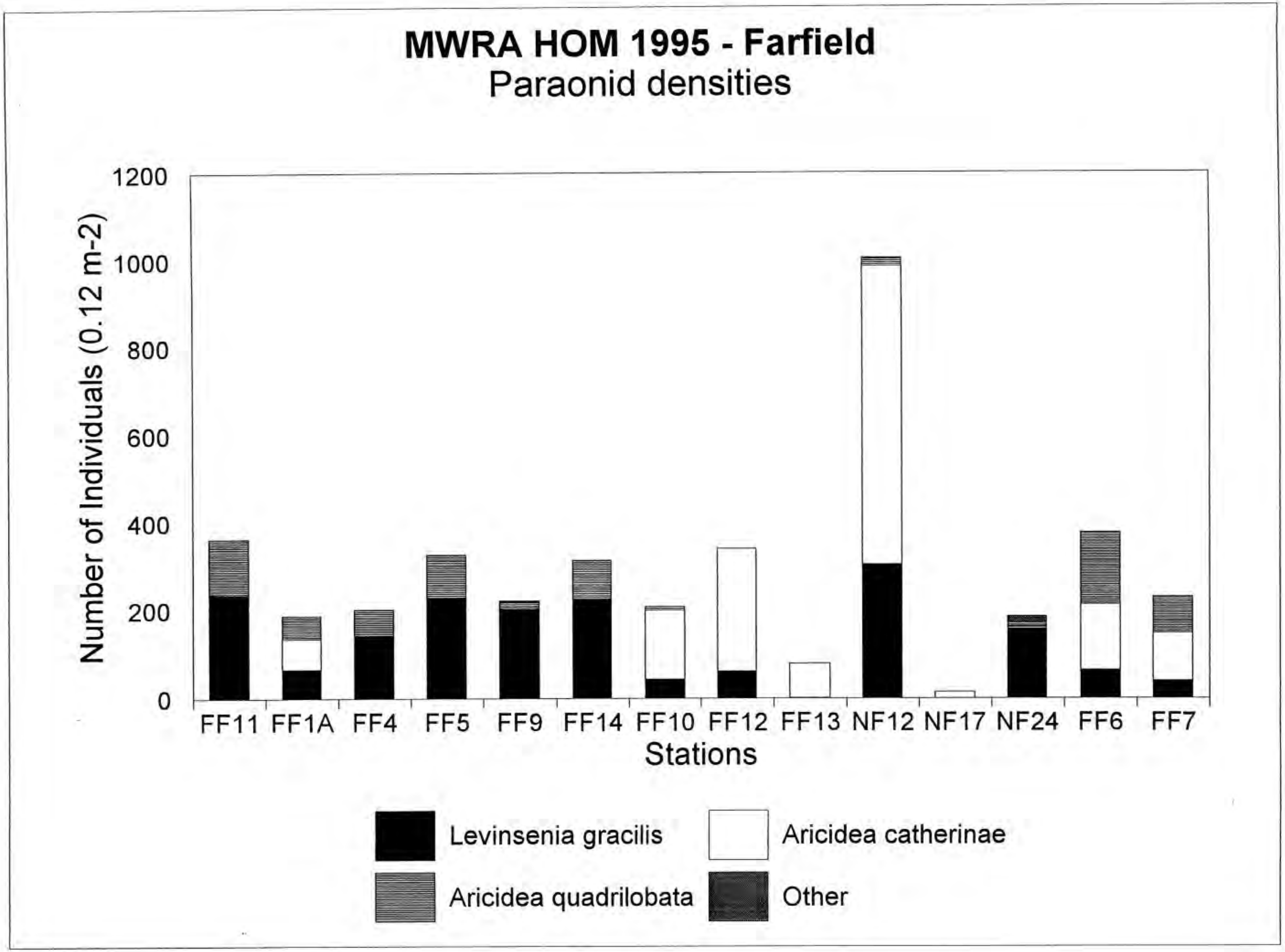
- **Other species commonly among top ten species: *Tharyx acutus*, *Aphelochaeta marioni*, and *Monticellina baptisteae* (Cirratulidae). Peak densities of *T. acutus* about 11,000 individuals per m^2, in Midfield; densities also high at station FF6 (Cape Cod Bay). Peak densities of *A. marioni* and *M. baptisteae* in Mid- and Nearfield, roughly 5,000 individuals per m^2. Cirratulid densities in Farfield low, mostly *Chaetozone setosa*.**

- **Other important dominant species, densities moderate: paraonid polychaetes. *Levinsenia gracilis* present throughout; *Aricidea catherinae* most abundant in shallower water, replaced by *A. quadrilobata* offshore.**

- **Dominants typical for Cape Cod Bay: *Cossura longocirrata*, Tubificidae sp. 2, and *Apistobranchus typicus*.**



MWRA HOM 1995 - Farfield
Cirratulid densities


MWRA HOM 1995 - Farfield
Paraonid densities
Number of Individuals (0.12 m-2)
1200
1000
800
600
400
200
0
FF11
FF1A
FF4
FF5
FF9
FF14
FF10
FF12
FF13
NF12
NF17
NF24
FF6
FF7
Stations
Levinsenia gracilis
Aricidea catherinae
Aricidea quadrilobata
Other

SPECIES RICHNESS AND DIVERSITY IN THE FARFIELD

- Number of species per 0.12m^2 (three 0.04-m^2 grabs) varied between 56 and 108, for most stations between 60 and 80; slightly higher than in Nearfield, may be biased by sampling design. Lowest number of species at stations FF4 (Stellwagen Basin) and FF13 (Midfield), highest at stations FF9 (central Massachusetts Bay) and FF12 (Midfield).

- Total infaunal density slightly lower than in Nearfield, consistent with drop in species richness toward offshore in Nearfield area; range 1,100 to 8,000 individuals per 0.12m^2.

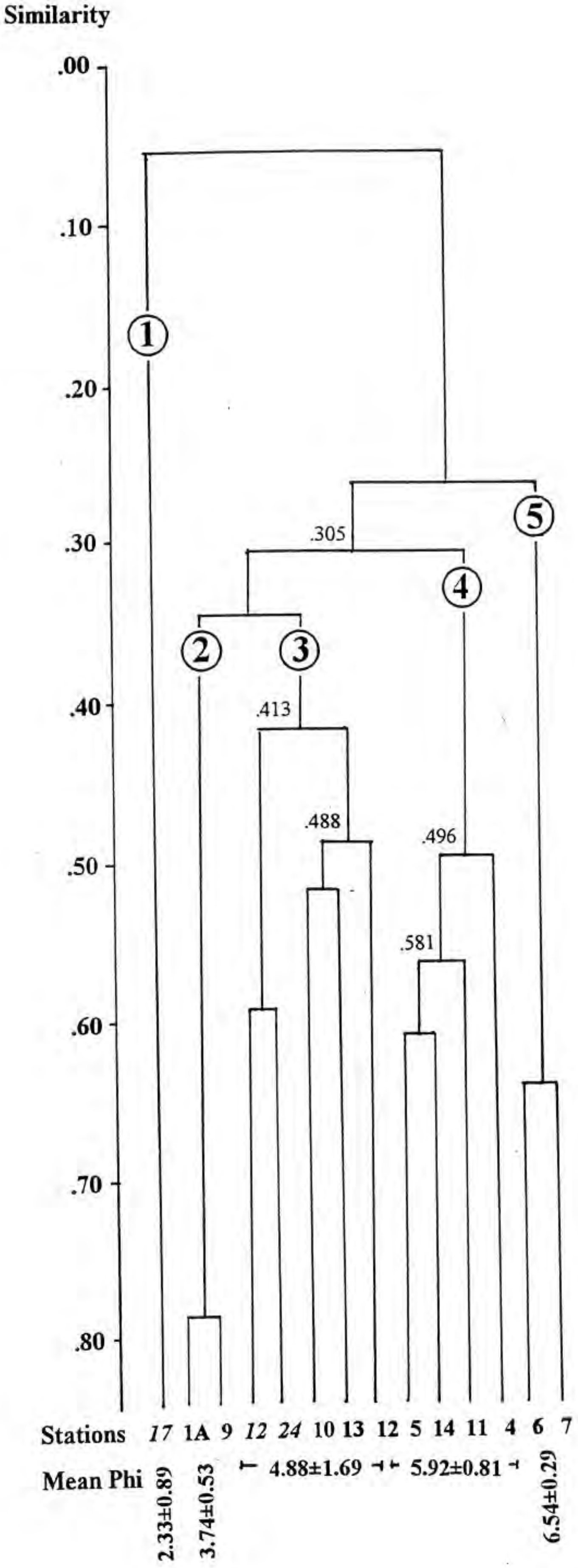
- Diversity, expressed as number of species per 100 individuals, ranged from about 16 to 30, similar to Nearfield. Lowest diversity index found for station FF9, center of Massachusetts Bay; highest index found for station FF10 (Midfield).

COMMUNITY ANALYSIS, FARFIELD STATIONS

- Similarity among the Farfield stations was measured with Bray-Curtis and Gallagher's CNESS.

- As in Nearfield, stations group by sediment grain size with both techniques. The very coarse-grained station NF17 is an outlier in both dendrograms.

- Cluster 2 of Bray-Curtis dendrogram includes stations with very high abundances of *Prionospio steenstrupi*; sediments are fine sands (mena phi 3.74±0.53) (FF1A and FF9). Cluster 3 includes Near- and Midfield stations with sediments mixed fine sands and clays (mean phi 4.88±1.69); subdominant species include *Monticellina baptisteae* and *Aricidea catherinae*. Cluster 4 contains offshore Massachusetts Bay stations, subdominant species including *Chaetozone setosa* and *Tubificoides apectinatus*, sediments silt and clay (mean phi 5.92±0.81). Cape Cod Bay stations grouped together in cluster 5 because of unusual dominant species; sediments very fine, mean phi 6.54±0.29.


Similarity
.00
.10
.20
.30
.40
.50
.60
.70
.80
①
②
③
④
⑤
.305
.413
.488
.496
.581
Stations 17 1A 9 12 24 10 13 12 5 14 11 4 6 7
Mean Phi
2.33±0.89
3.74±0.53
4.88±1.69
5.92±0.81
6.54±0.29

POST-DISCHARGE HYPOTHESES FOR BENTHIC BIOLOGY

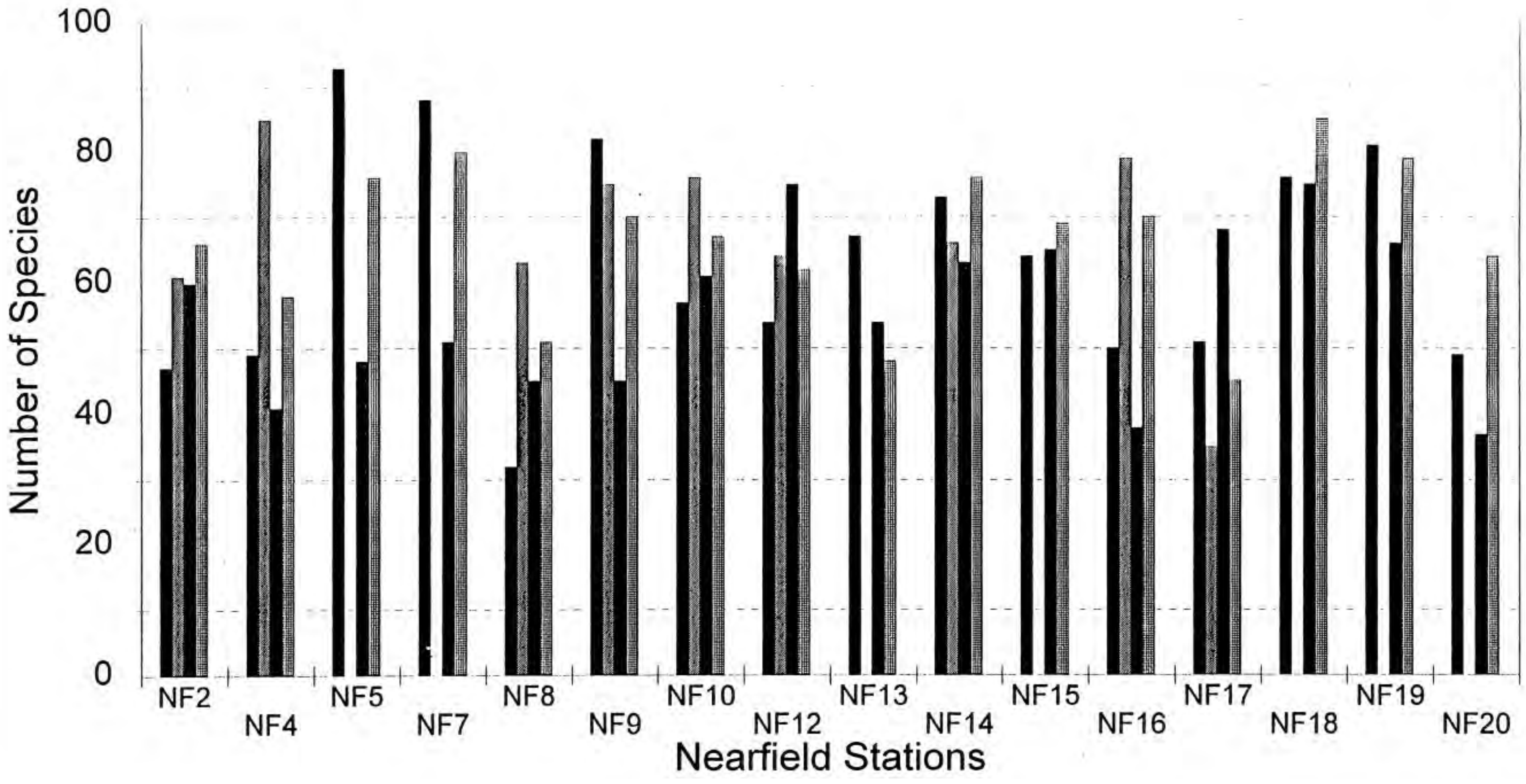
- **B1:** *The mean species diversity at nearfield muddy stations will not decrease to 50% of that measured during baseline monitoring.*
- **B2:** *The mean species diversity at nearfield coarse-grained stations will not decrease to 50% of that measured during baseline monitoring.*
- **B3:** *The mean species diversity of midfield stations 2-7 km from the outfall will not exhibit a significant downward trend measured over any three (3) consecutive post-discharge years.*
- **B4:** *The benthic infaunal composition of midfield communities will not change from the baseline assemblages to those typical of a degraded benthic community.*
- **Alternate B1:** *Species composition and relative abundance patterns of benthic communities at stable midfield soft-bottom stations will not depart significantly from those measured during baseline monitoring.*

YEAR TO YEAR TRENDS IN BENTHIC COMMUNITY PARAMETERS AT THE NEARFIELD MONITORING SITE

- **Number of Species occurring at most stations in the nearfield area varies from ± 30-50 species from one year to the next. The exceptions appear to be NF Stations 2, 10, 12, 13, 14, and 15 where this parameter varies only by ± 10-20 species.**

- **Number of Individuals per area (density) varies widely from one year to the next; 1993 was generally a low-density year.**

- **Species Diversity as measured by Shannon-Wiener (H′) varies most at NF Stations 2 and 17 (±1.0 to 1.25), approaching the 50% limit of the proposed hypotheses.**

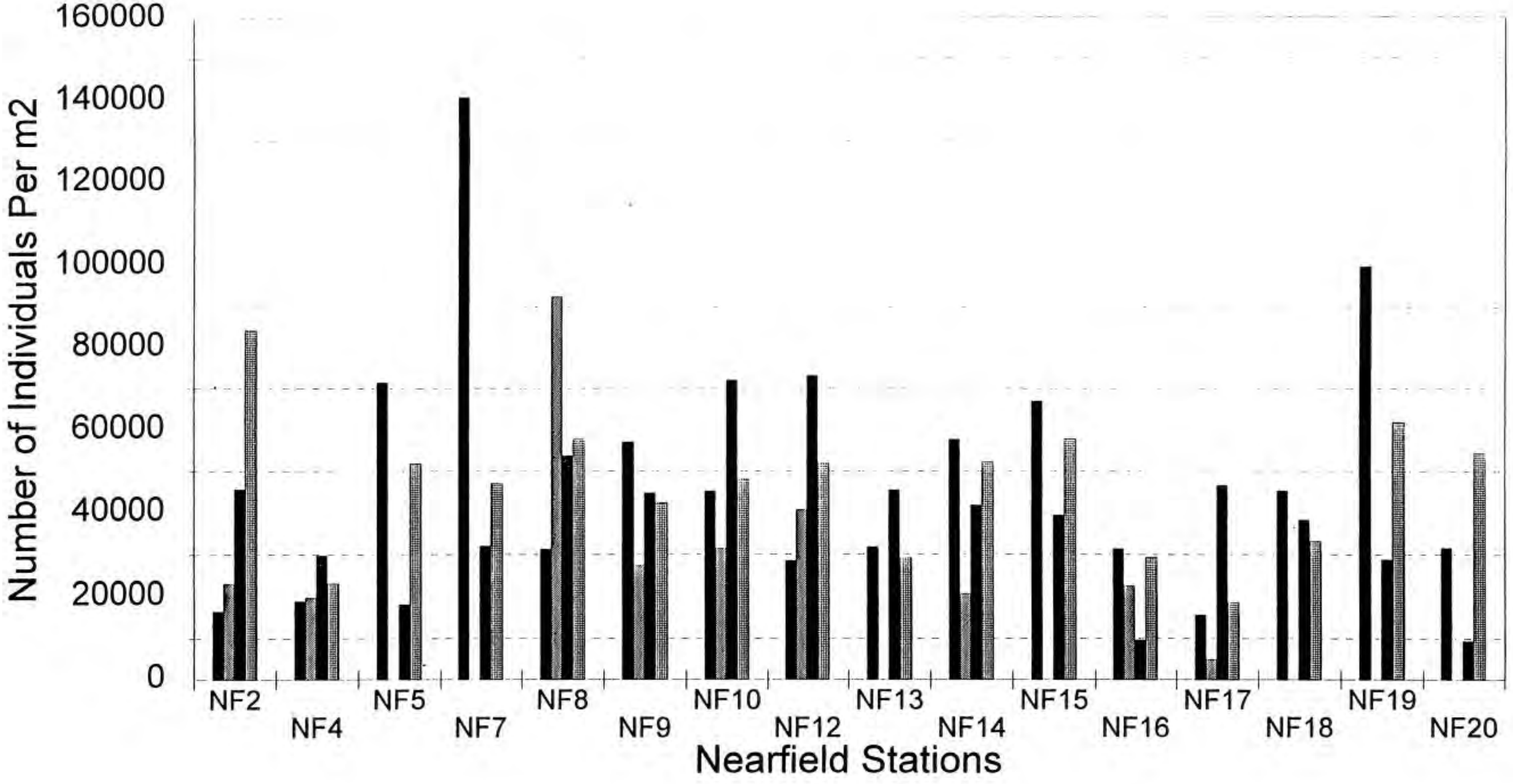


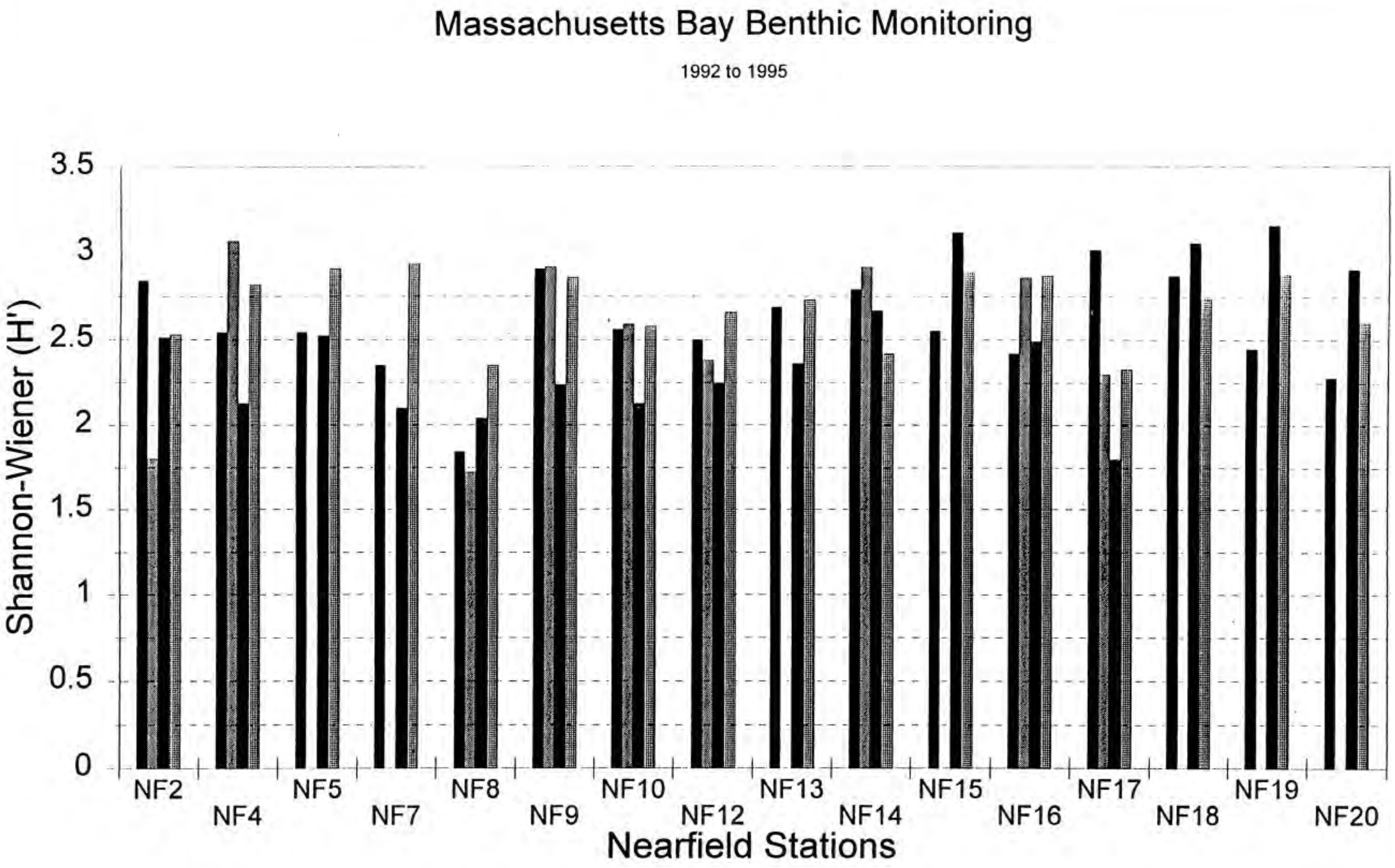
Massachusetts Bay Benthic Monitoring

1992 to 1995

Massachusetts Bay Benthic Monitoring

1992 to 1995




Massachusetts Bay Benthic Monitoring
1992 to 1995
Shannon-Wiener (H')
3.5
3
2.5
2
1.5
1
0.5
0
NF2
NF4
NF5
NF7
NF8
NF9
NF10
NF12
NF13
NF14
NF15
NF16
NF17
NF18
NF19
NF20
Nearfield Stations

YEAR TO YEAR TRENDS IN BENTHIC COMMUNITY PARAMETERS AT THE FARFIELD MONITORING SITES

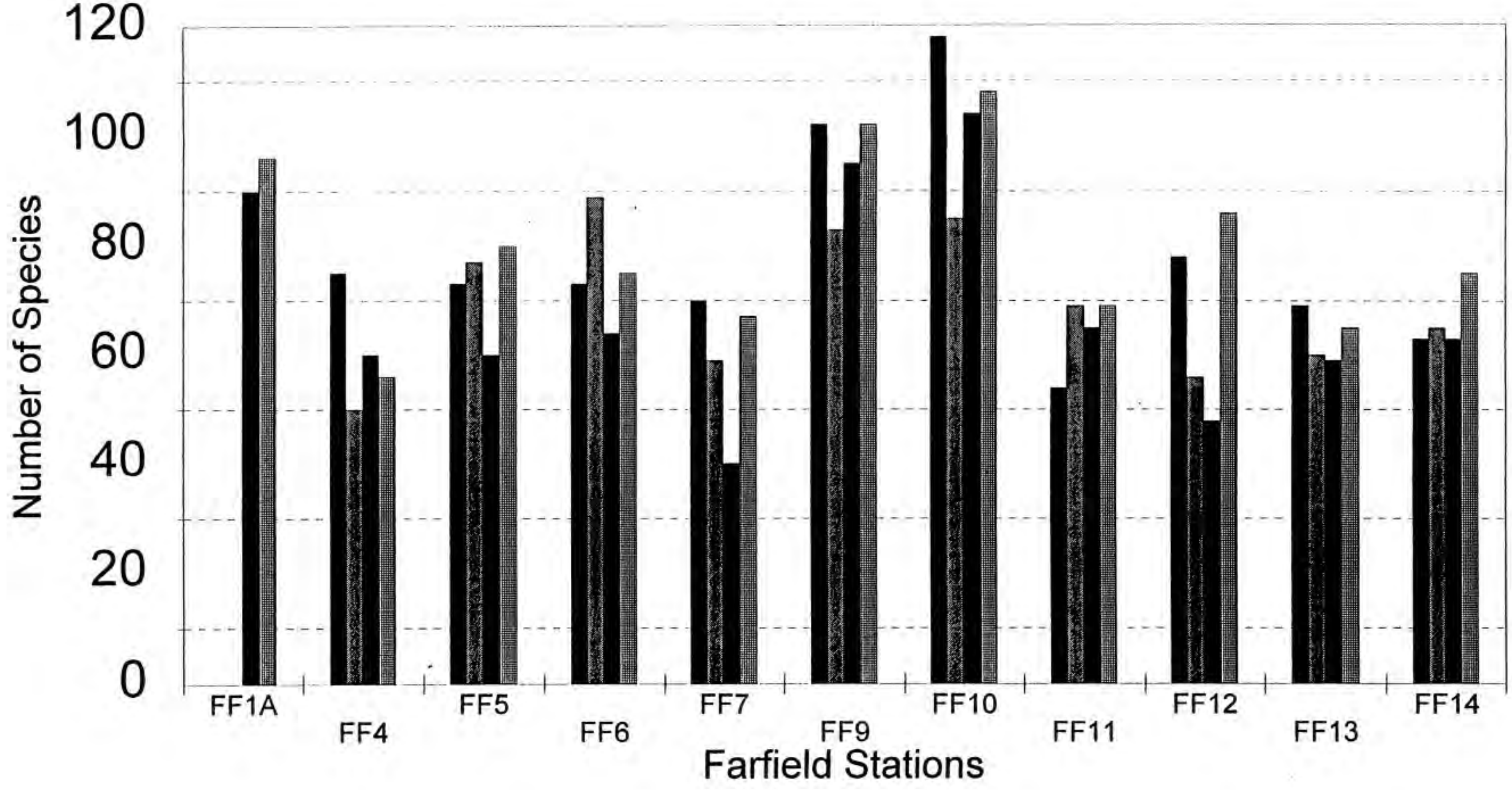
- Number of Species occurring at any given station in the farfield area varies from ± 10-40 from one year to the next. These ranges are smaller than those for the nearfield and probably reflect the higher stability of data obtained from replicated sampling.

- Number of Individuals per area (density) varies widely from one year to the next; 1994 was generally a low-density year in contrast to 1993 in the nearfield. Wide variation in density is due to variation in recruitment of individual dominant species.

- Species Diversity as measured by Shannon-Wiener (H') varies most at FF Stations 1A and 5 (±1.25 to 1.60), approaching the 50% limit of the proposed nearfield hypotheses.

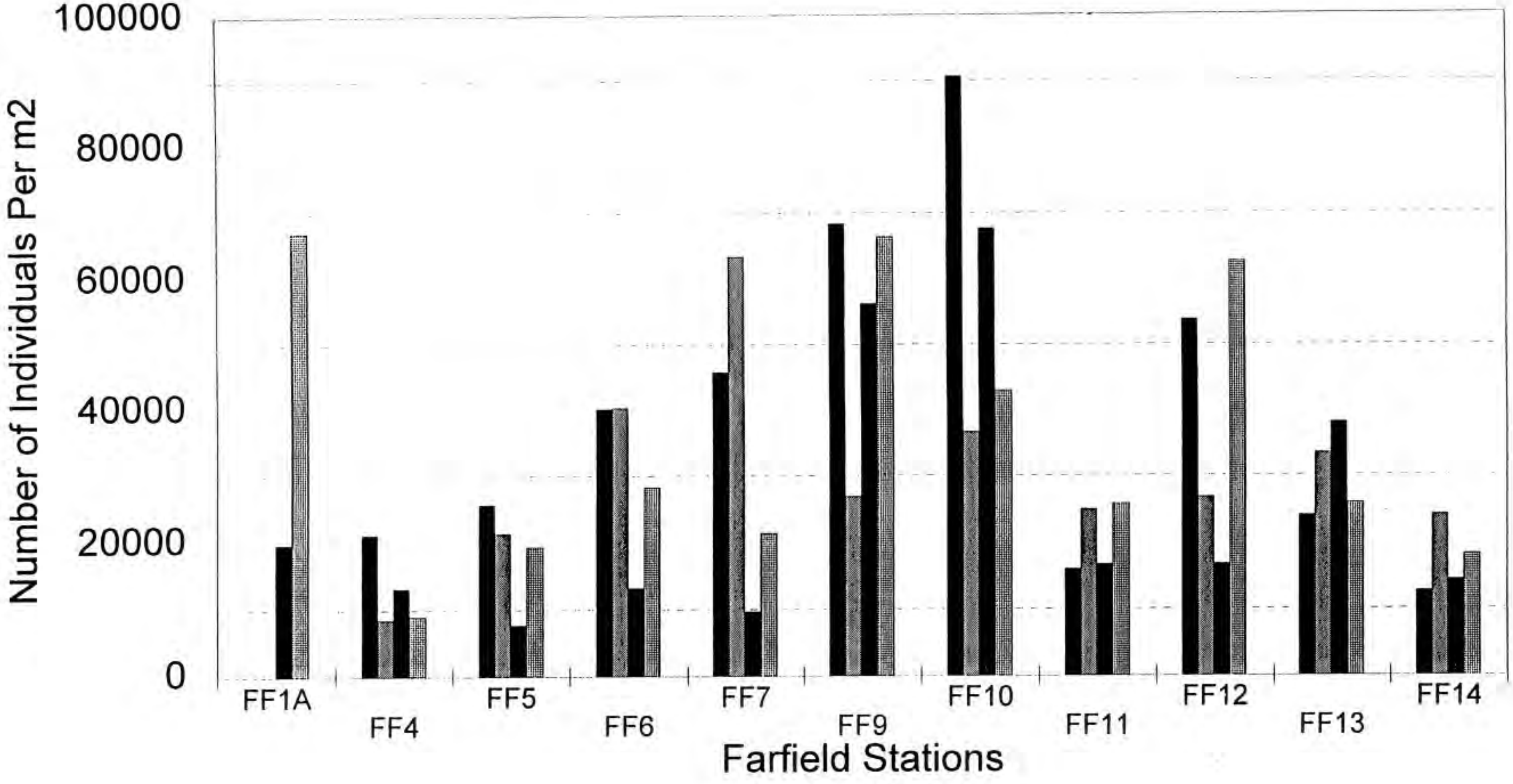
Massachusetts Bay Benthic Monitoring

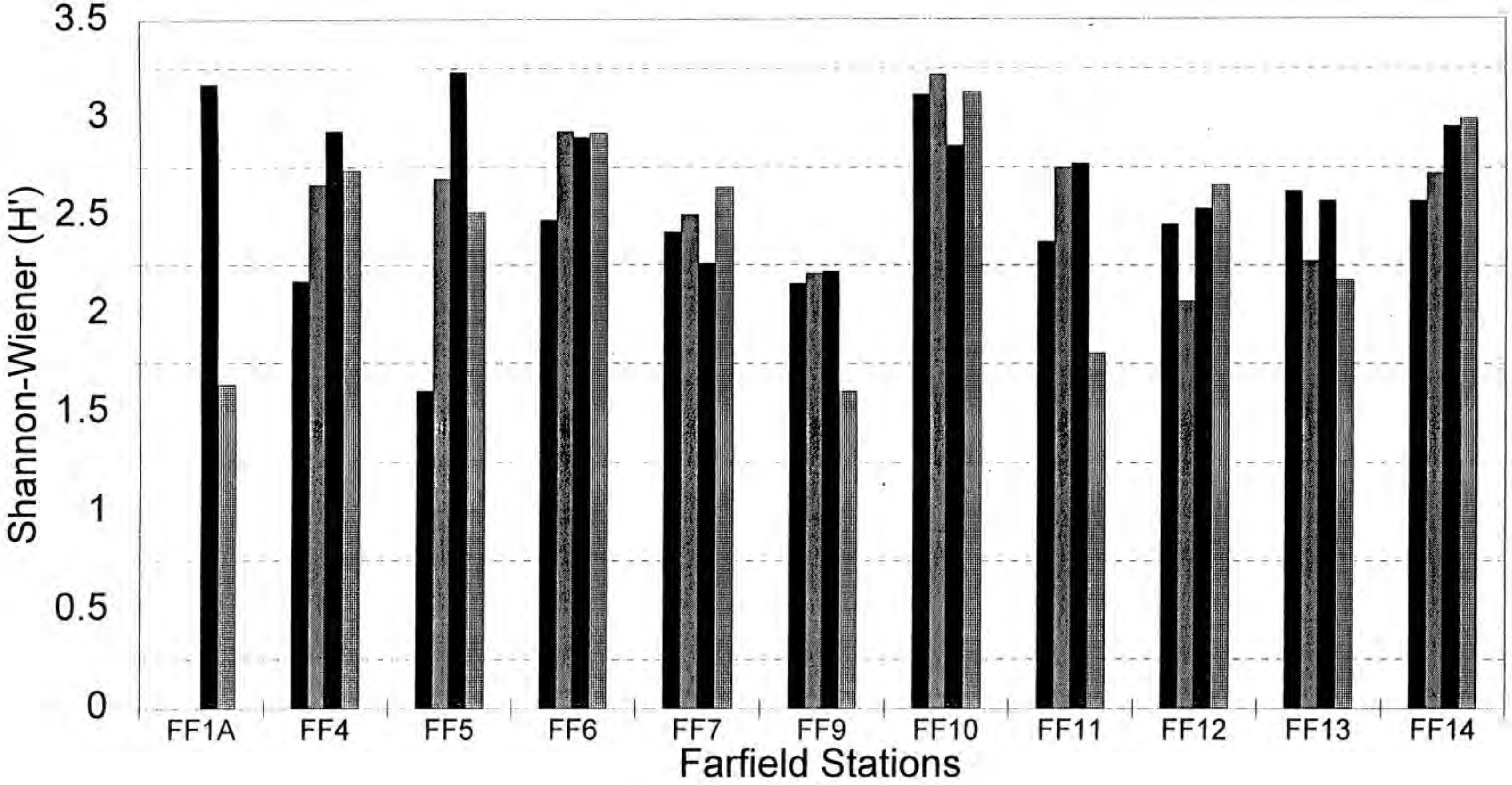
1992 to 1995



Massachusetts Bay Benthic Monitoring

1992 to 1995





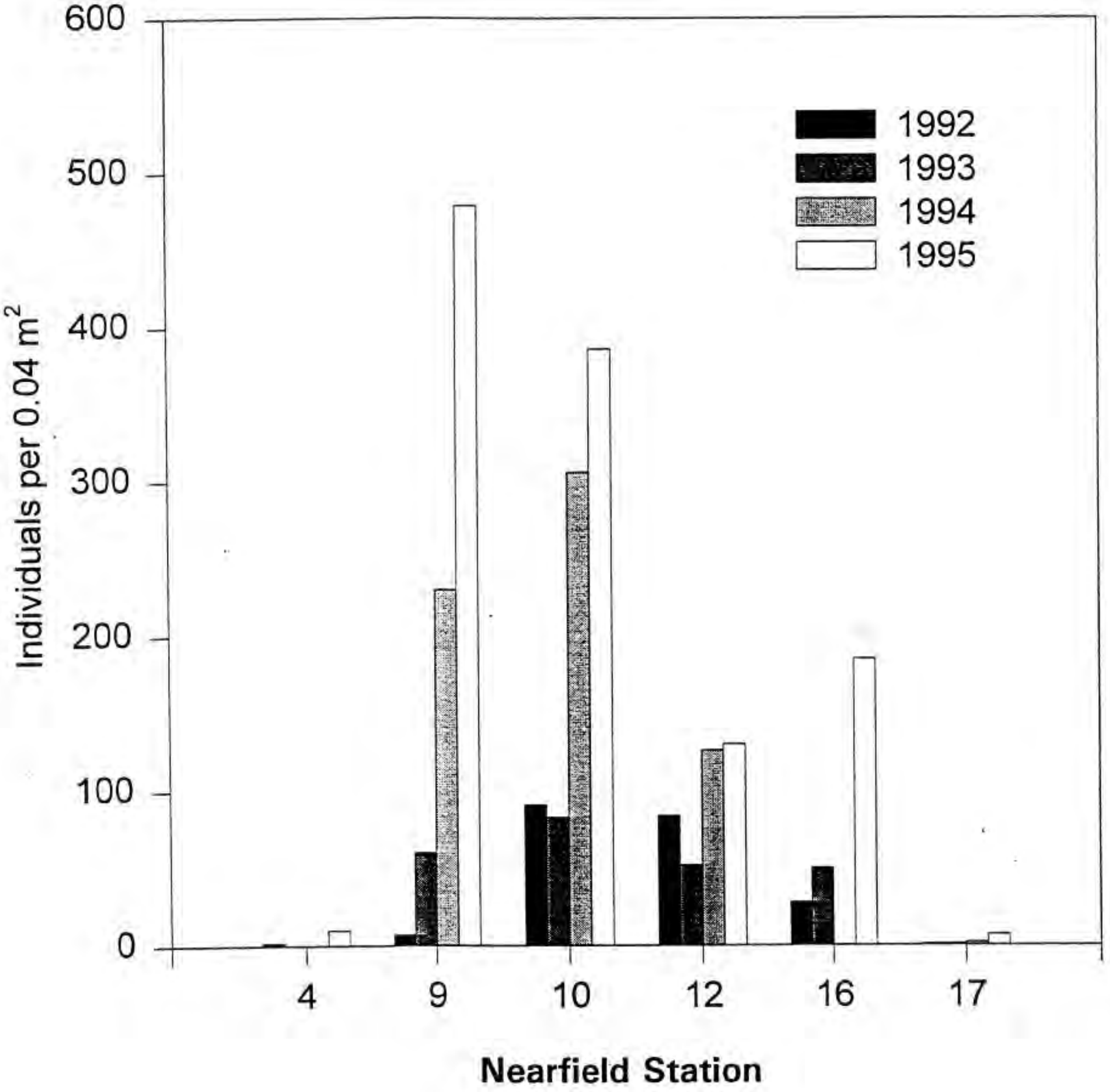
Massachusetts Bay Benthic Monitoring

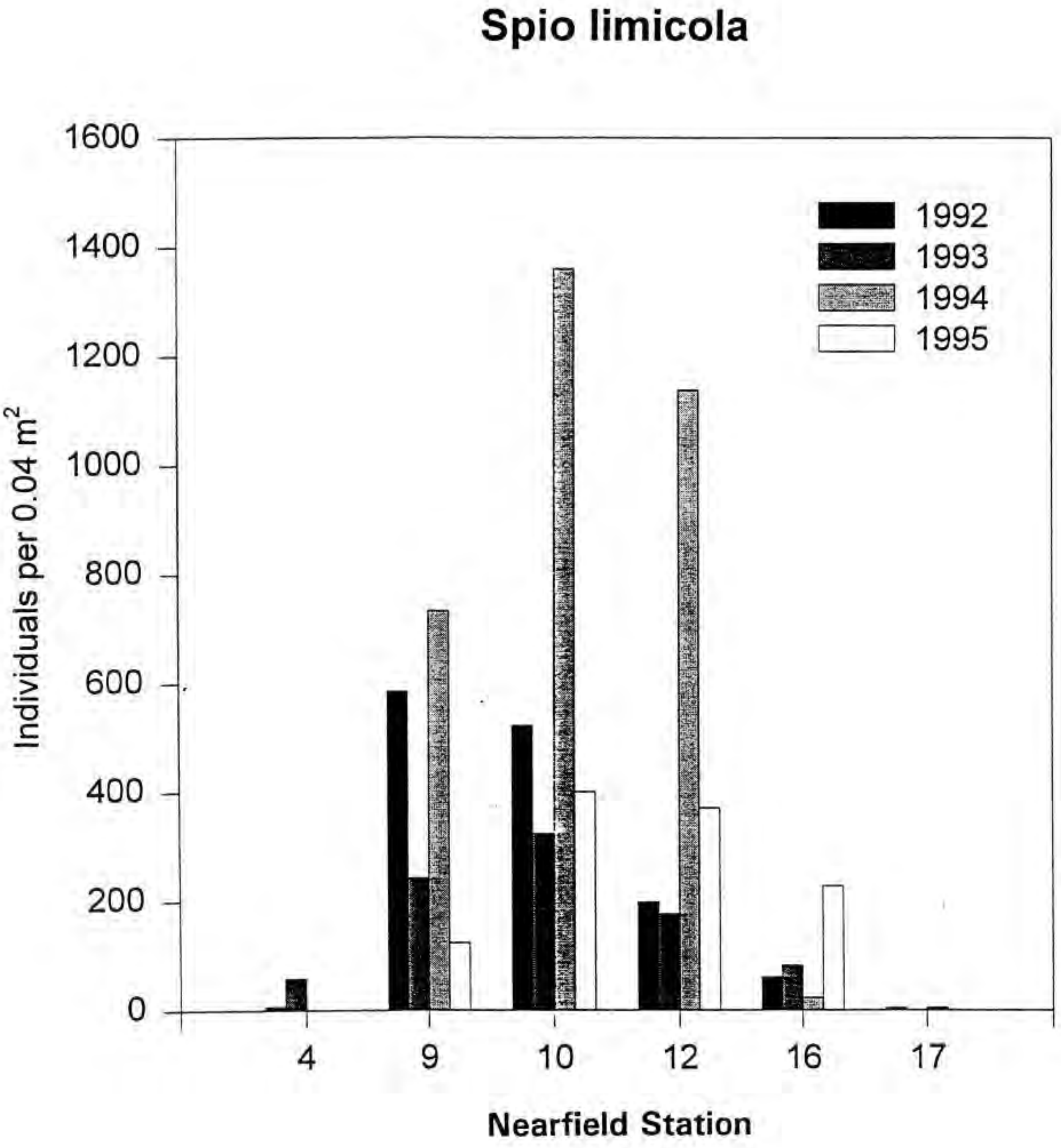
1992 to 1995

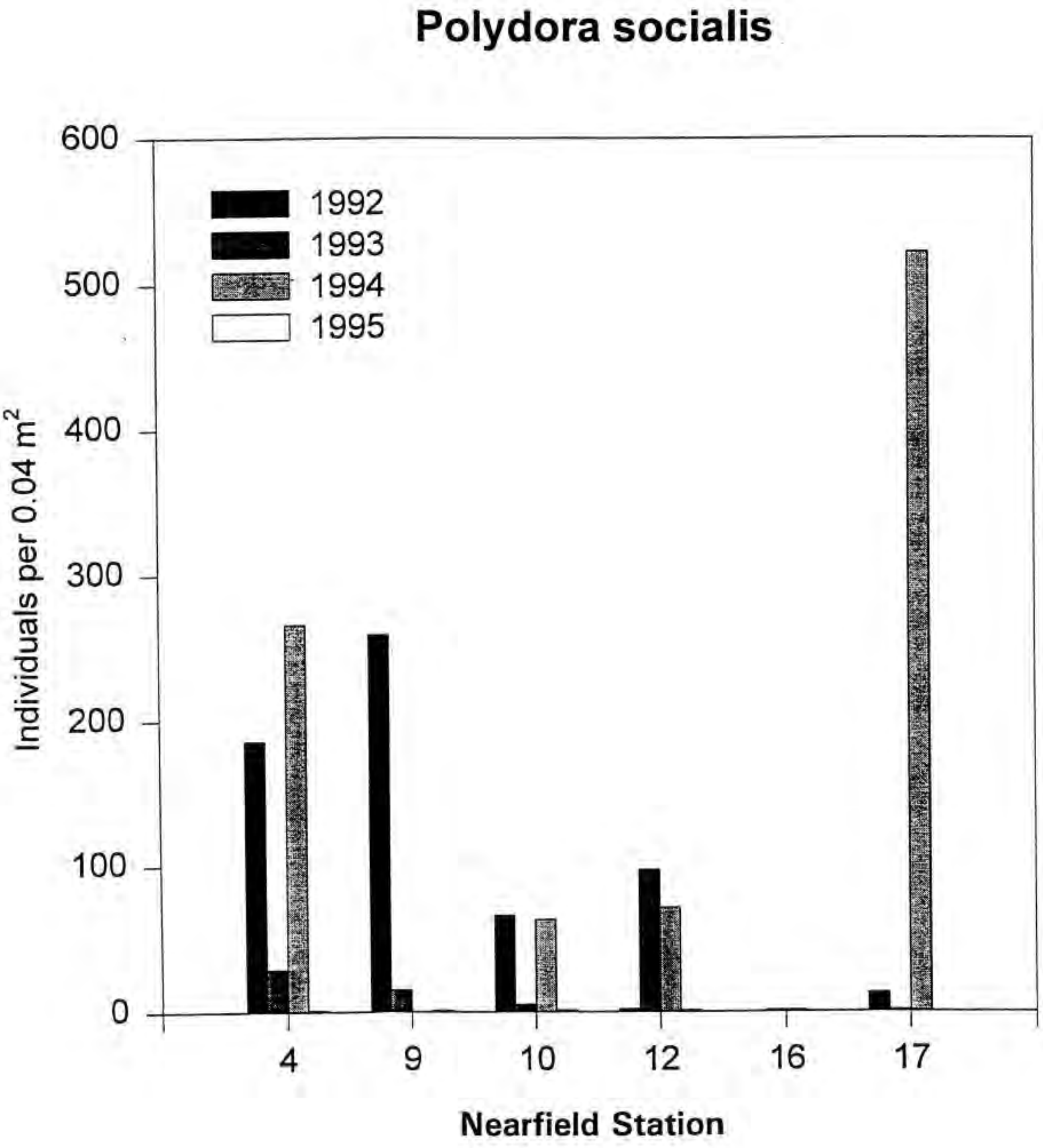
DENSITY OF DOMINANT NEARFIELD SPECIES

- Spionid polychaetes are characteristic of Massachusetts Bay faunal assemblages, but there are year to year shifts from one dominant species to another. *Prionospio steenstrupi* was the overwhelming dominant spionid in 1995, whereas *Polydora socialis* and *Spio limicola* predominated in 1992-1994. During the 1986-1987 STFP program, *Prionospio steenstrupi* was the dominant species at those stations near current nearfield stations.
- Polychaetes of the families Cirratulidae (*Tharyx*), Capitellidae (*Mediomastus*), and Paraonidae *(Aricidea*) appear to exhibit more year to year stability than spionids.
- Syllid polychaetes (*Exogone*) are characteristic of coarser sediments and while usually and consistent in their dominance and distributional patterns, do exhibit wide fluctation in year to year density.

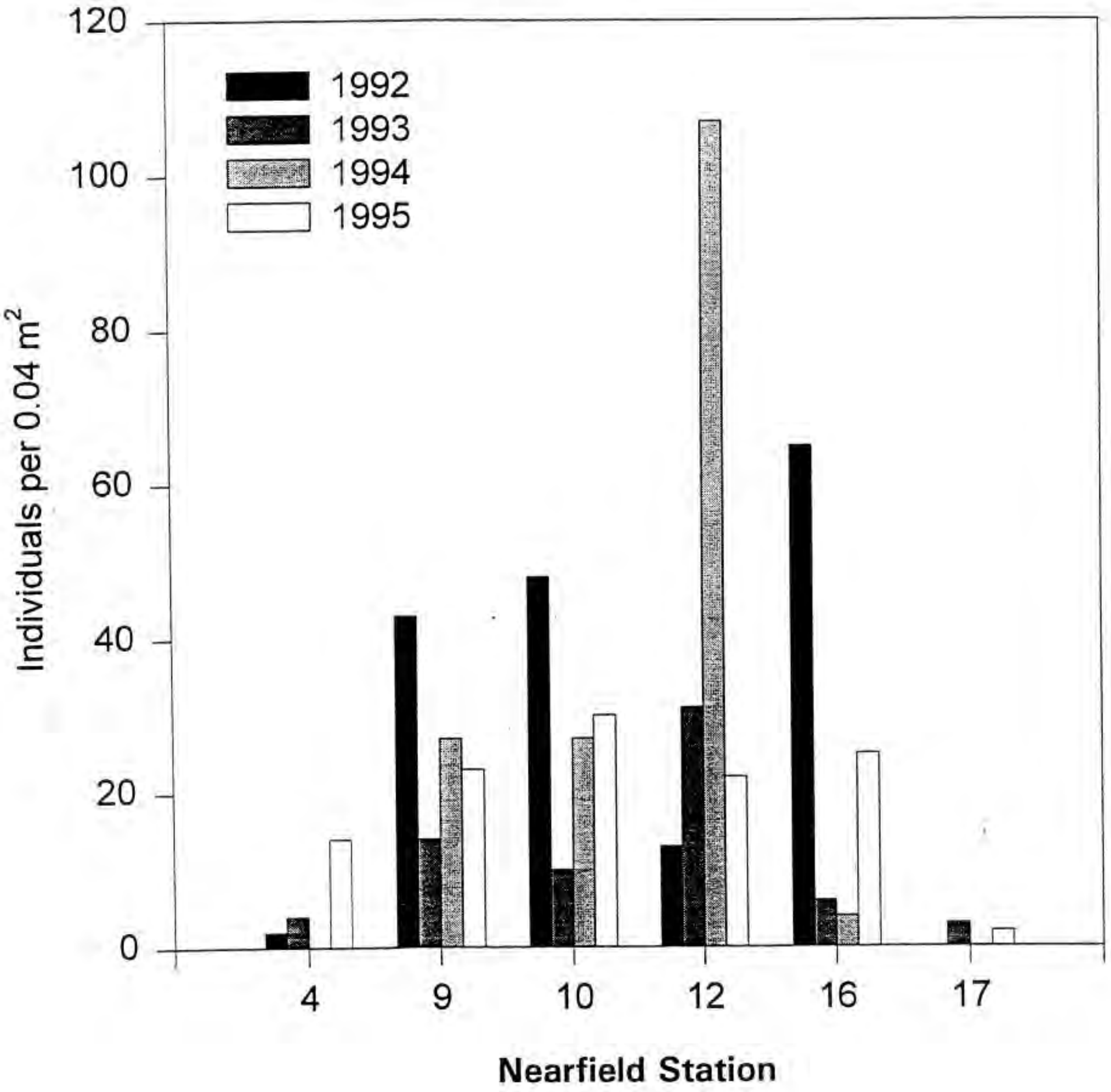
Prionospio steenstrupi

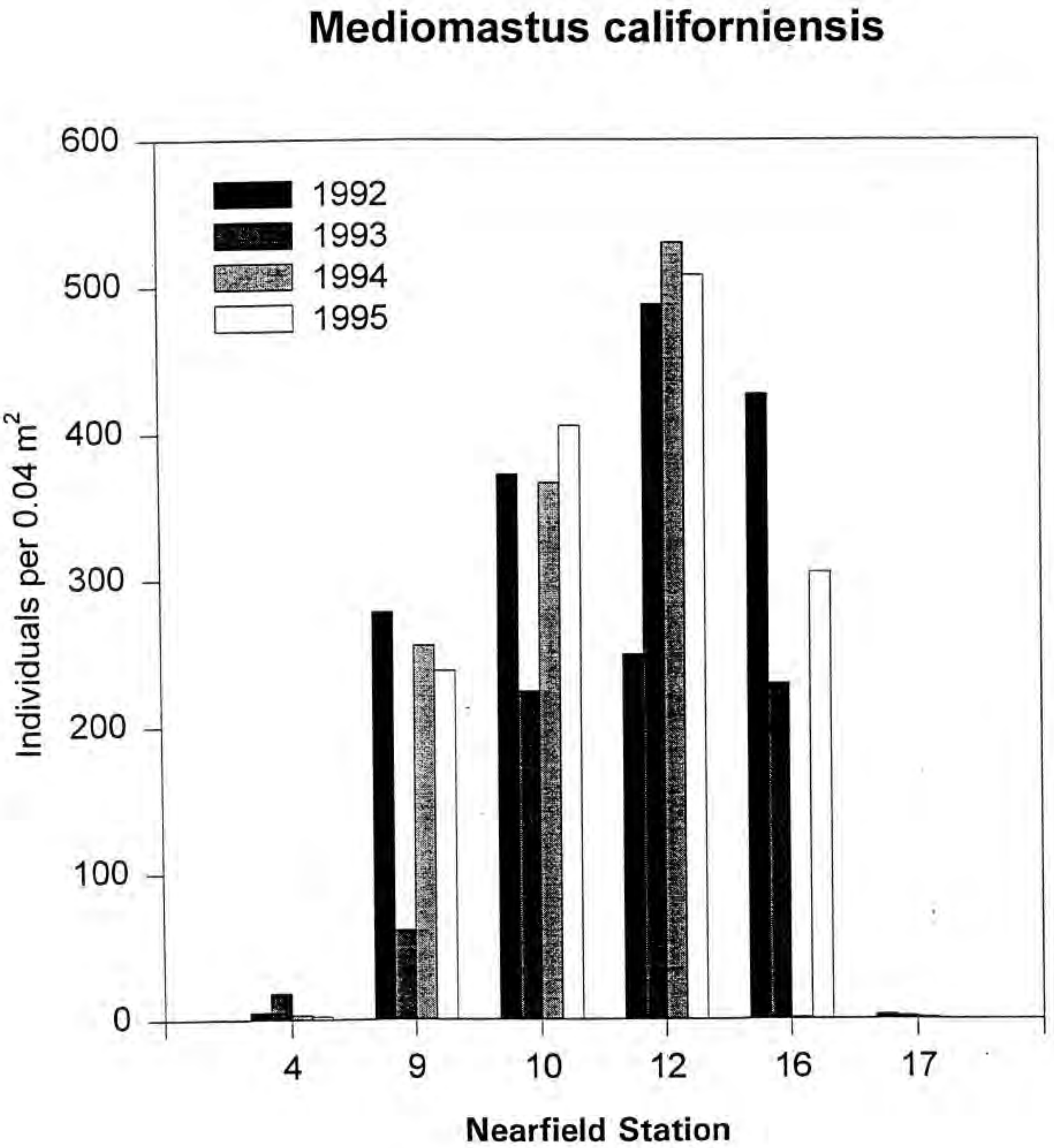



Spio limicola
1992
1993
1994
1995
Individuals per 0.04 m²
0
200
400
600
800
1000
1200
1400
1600
4
9
10
12
16
17
Nearfield Station

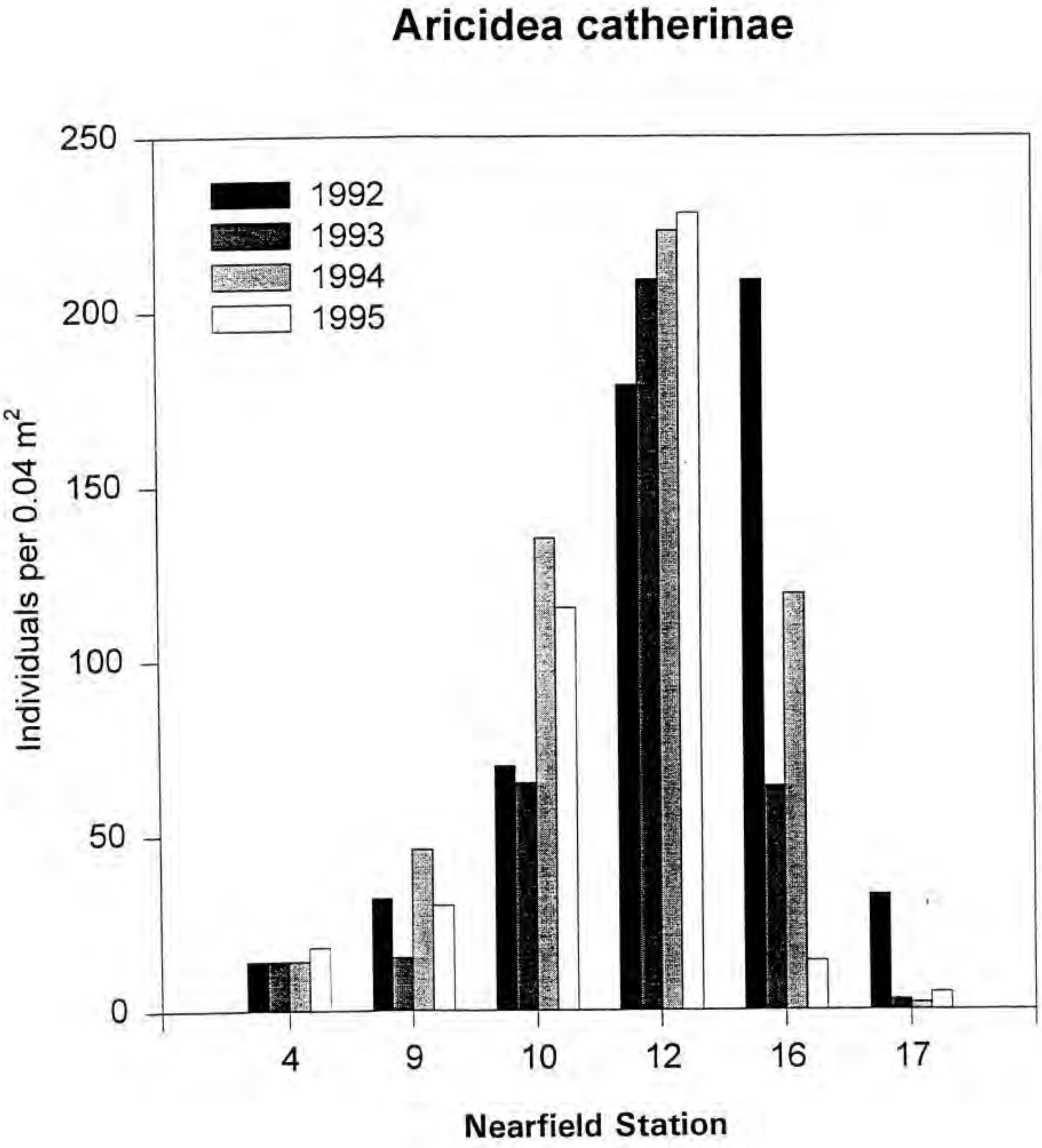

Polydora socialis
1992
1993
1994
1995
Individuals per 0.04 m2
600
500
400
300
200
100
0
4
9
10
12
16
17
Nearfield Station

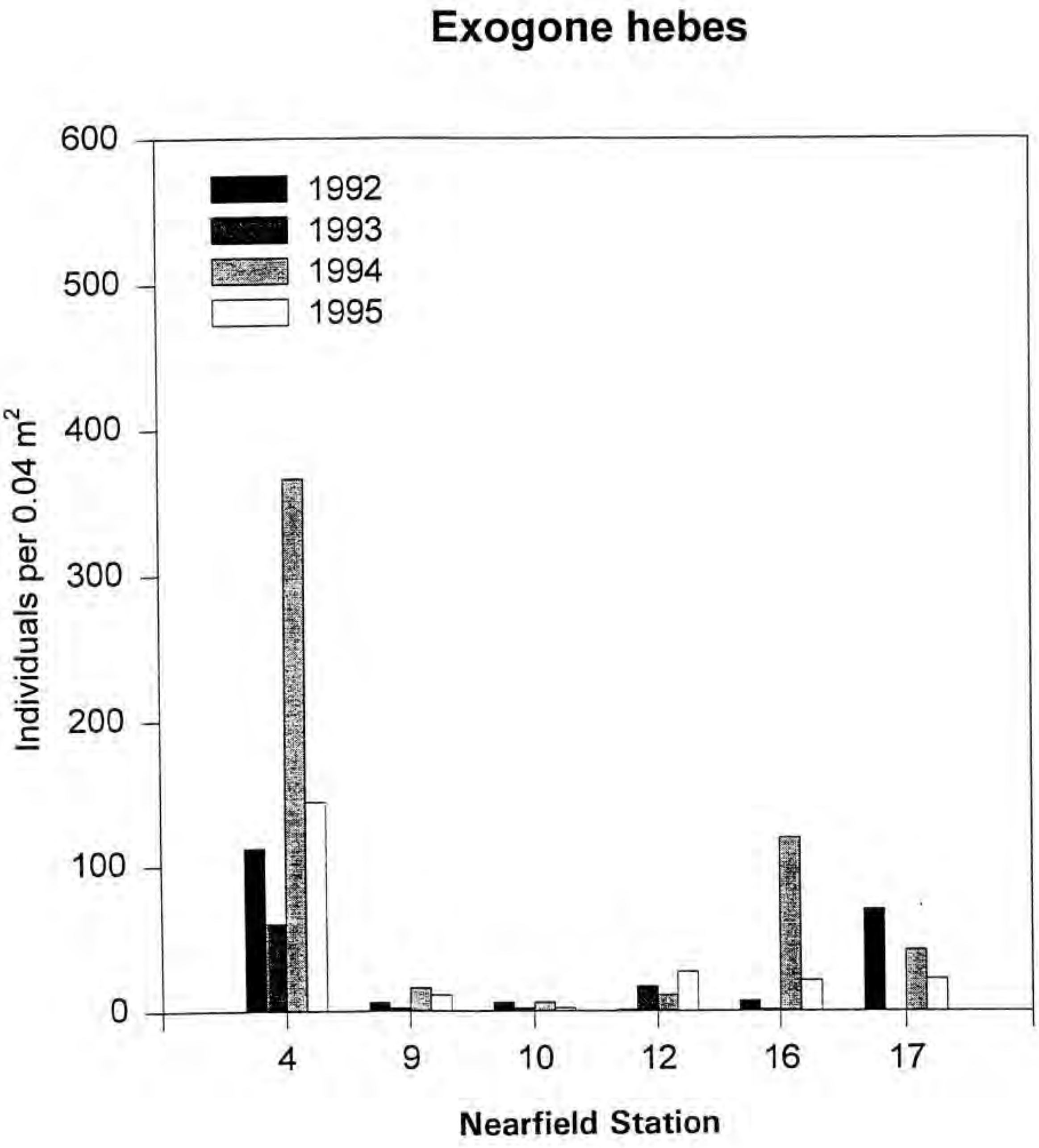
Tharyx acutus

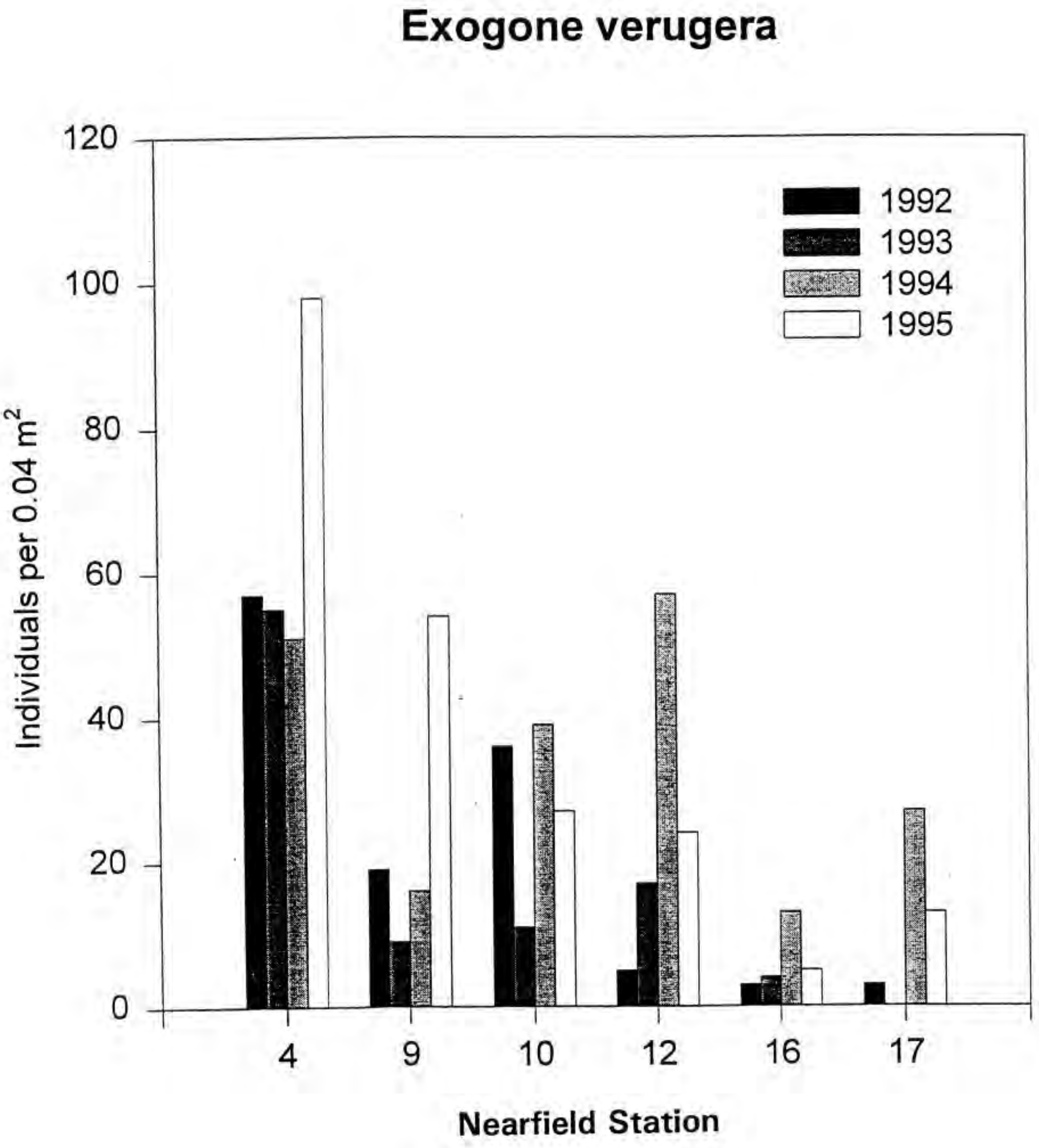




Mediomastus californiensis
600
500
400
300
200
100
0
1992
1993
1994
1995
Individuals per 0.04 m^2
4
9
10
12
16
17
Nearfield Station

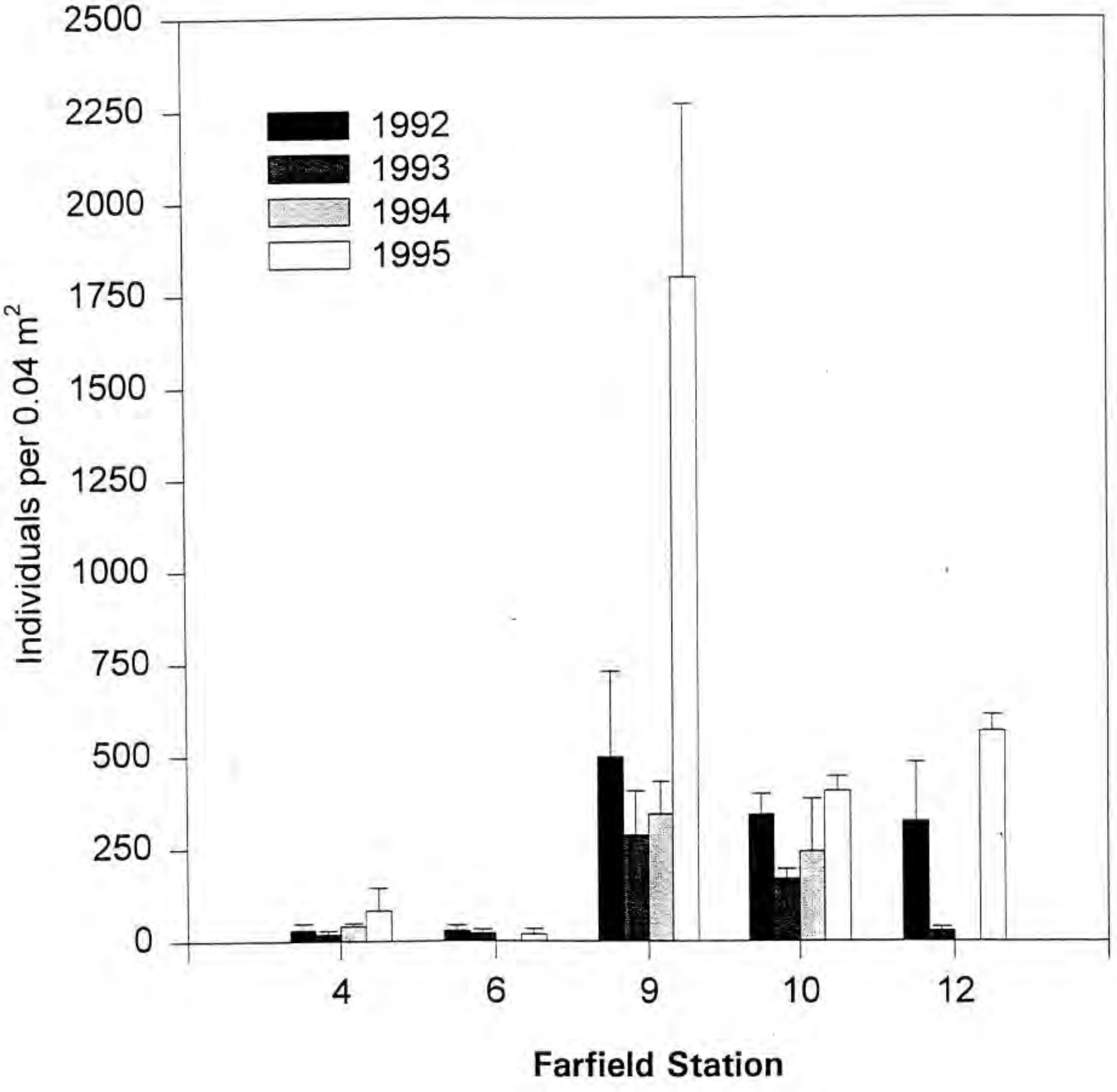

Aricidea catherinae
1992
1993
1994
1995
250
200
150
100
50
0
Individuals per 0.04 m^2
4
9
10
12
16
17
Nearfield Station


Exogone hebes
1992
1993
1994
1995
Individuals per 0.04 m²
600
500
400
300
200
100
0
4
9
10
12
16
17
Nearfield Station

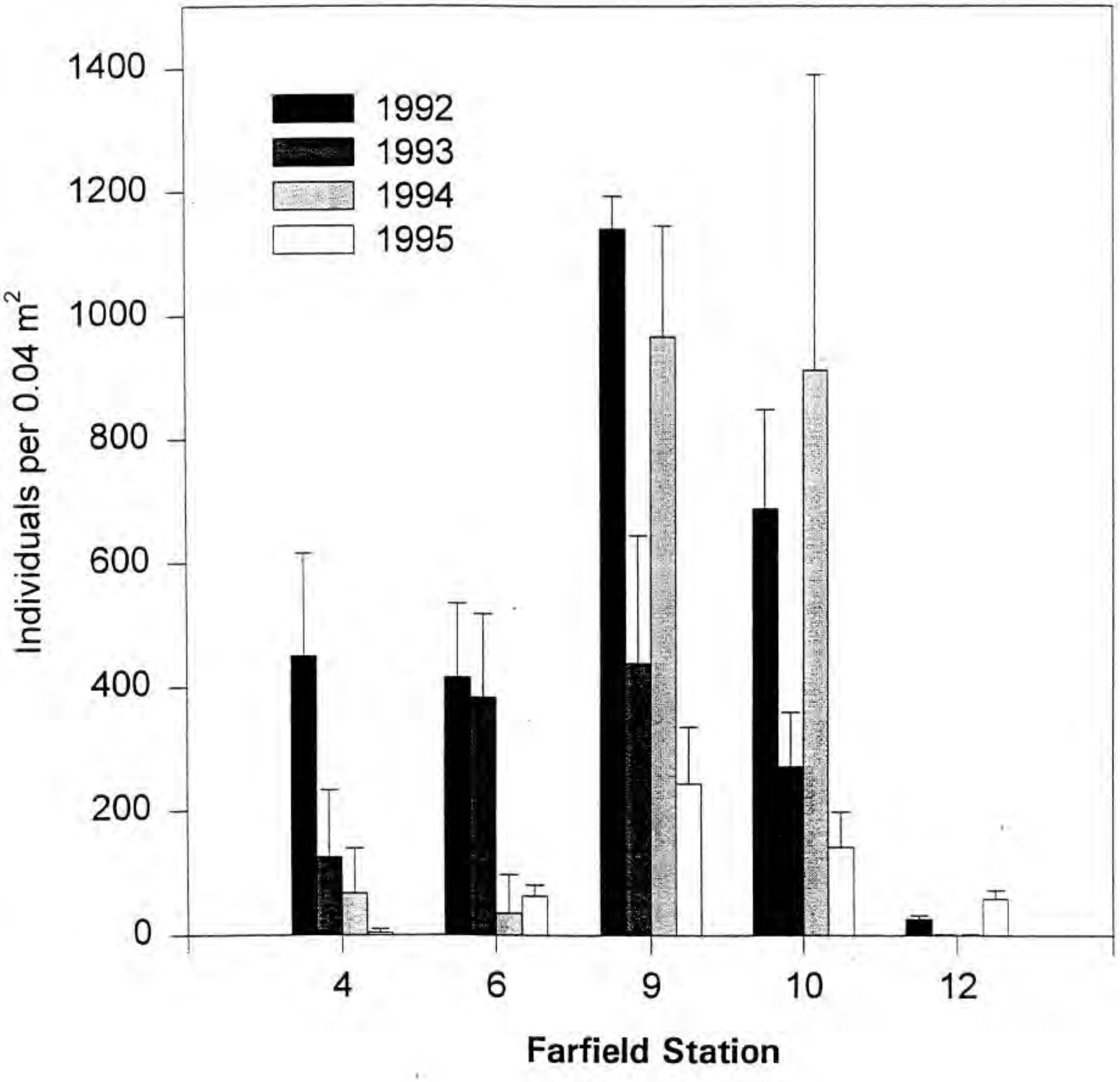

Exogone verugera
Individuals per 0.04 m²
0
20
40
60
80
100
120
1992
1993
1994
1995
4
9
10
12
16
17
Nearfield Station

DENSITY OF DOMINANT FARFIELD SPECIES

- Spionid polychaetes behave similarly in the nearfield and farfield. *Prionospio steenstrupi* was the overwhelming dominant spionid in 1995, whereas *Polydora socialis* and *Spio limicola* predominated in 1992-1994..
- Polychaetes of the families Cirratulidae (*Tharyx*), Capitellidae (*Mediomastus*), and Paraonidae *(Aricidea*) appear to exhibit more year to year variability at the farfield stations than at the nearfield.
- Cossurid polychaetes are only dominant at the Cape Cod Bay Stations.

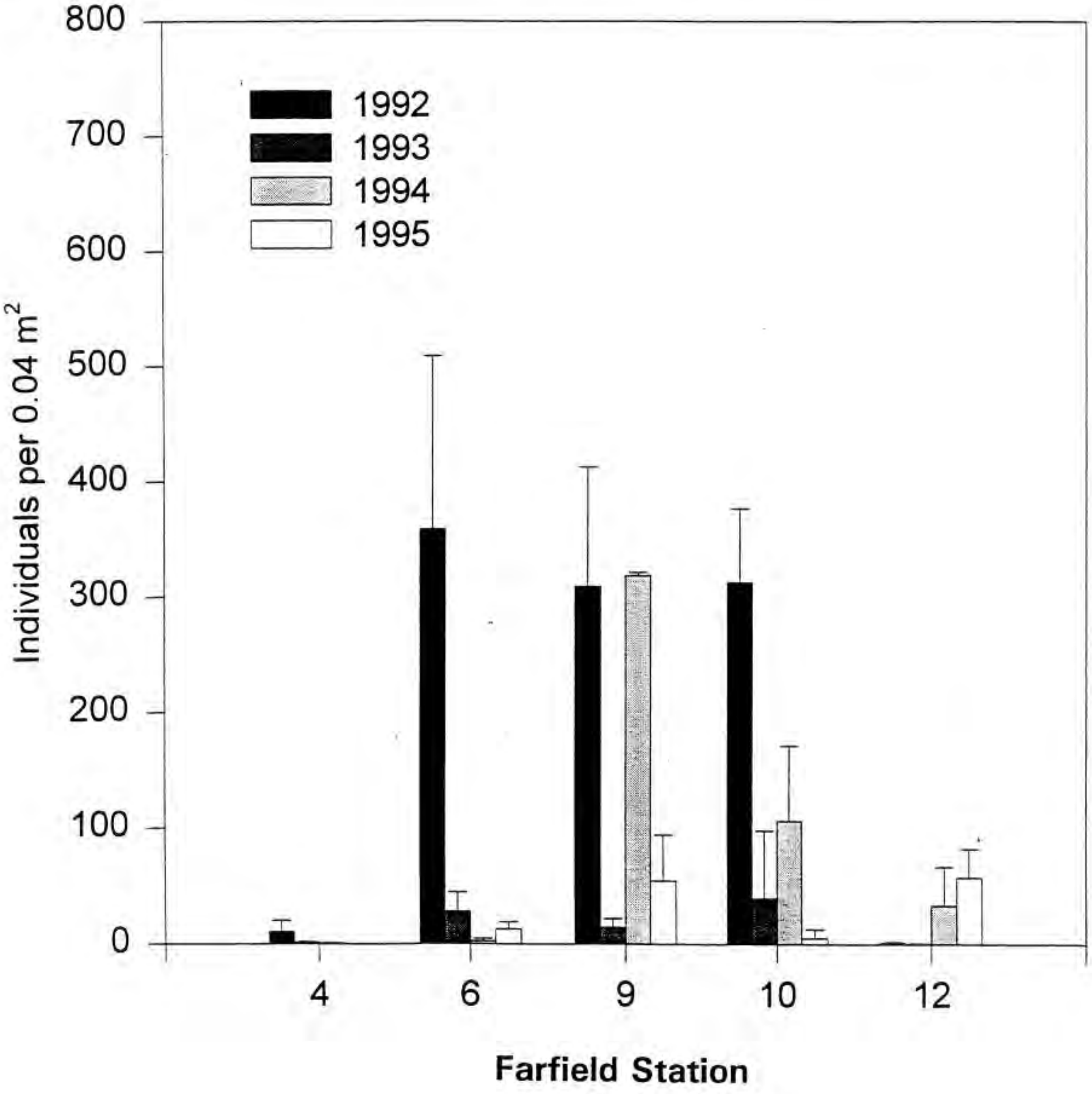


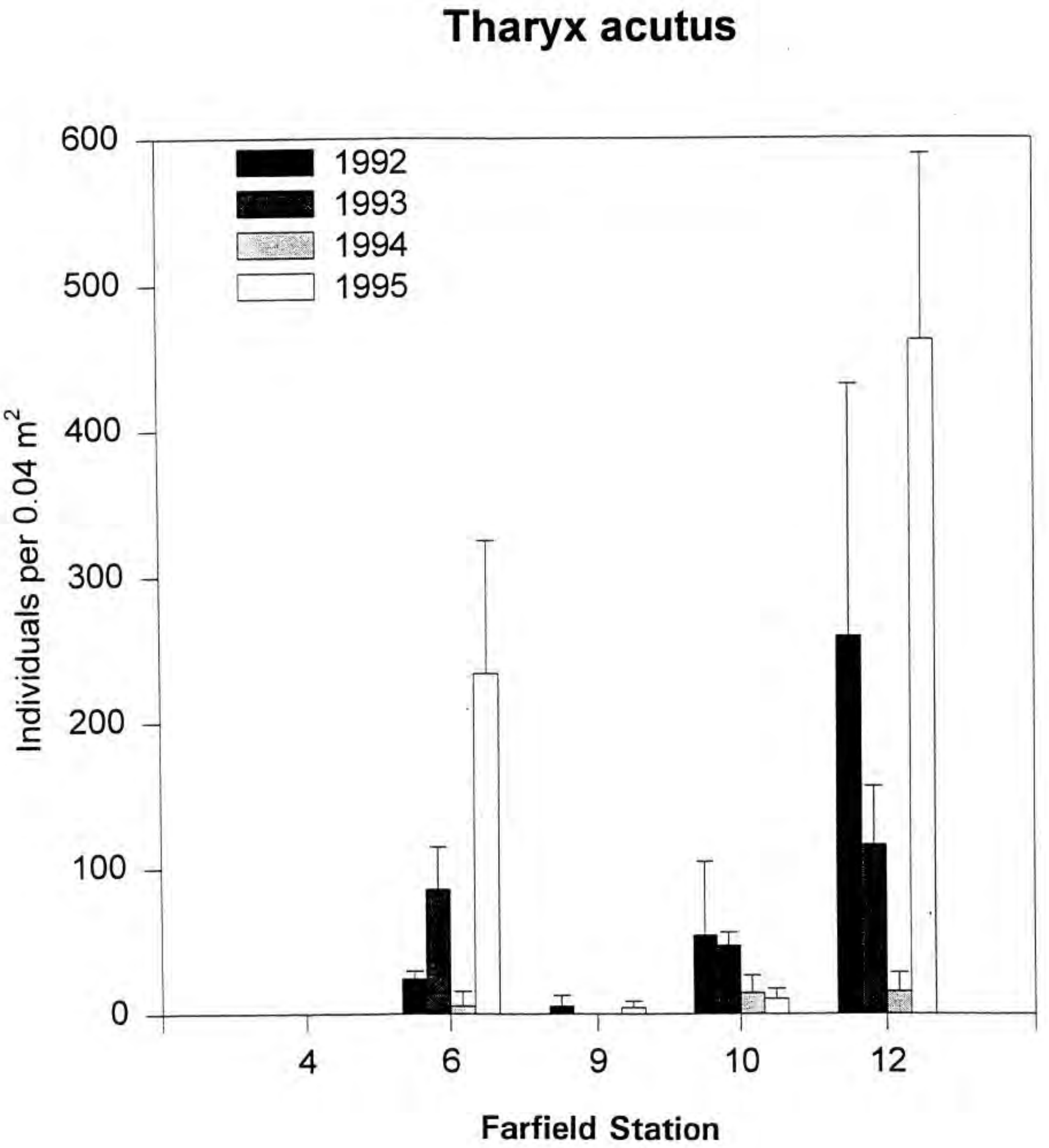
Prionospio steenstrupi

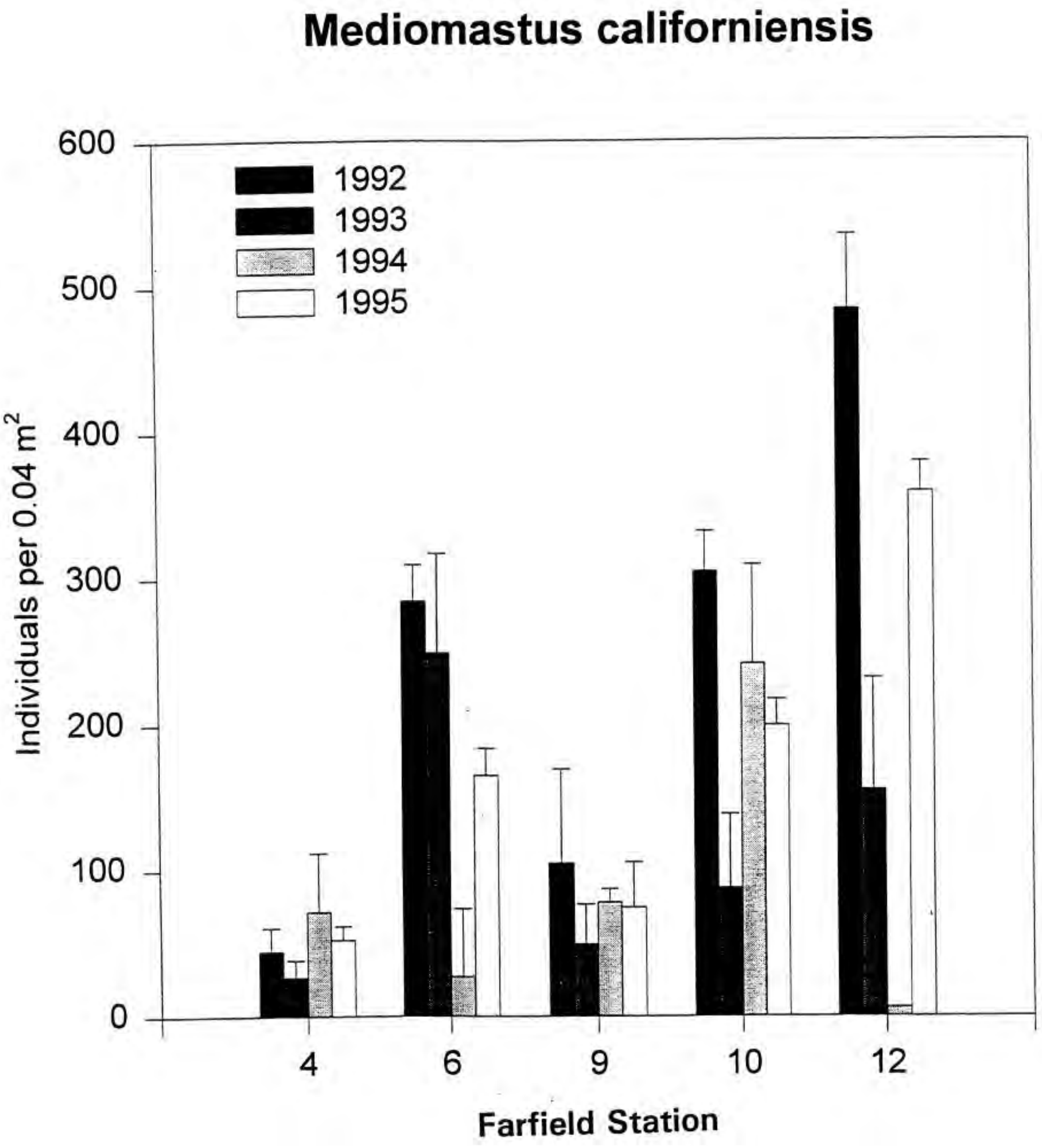


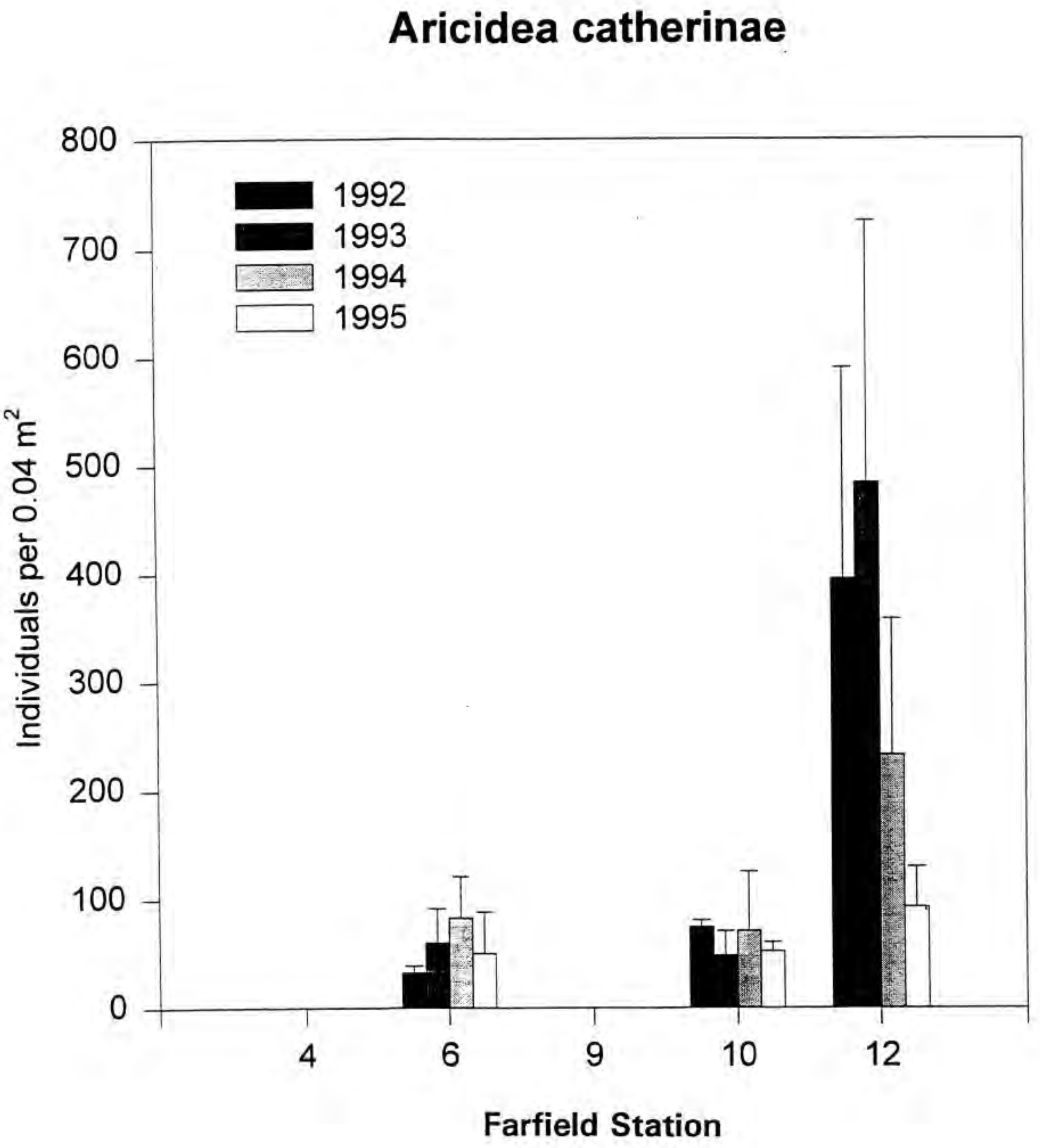
Spio limicola

Polydora socialis




Tharyx acutus
1992
1993
1994
1995
Individuals per 0.04 m^2
0
100
200
300
400
500
600
4
6
9
10
12
Farfield Station


Mediomastus californiensis
1992
1993
1994
1995
Individuals per 0.04 m^2
600
500
400
300
200
100
0
4
6
9
10
12
Farfield Station

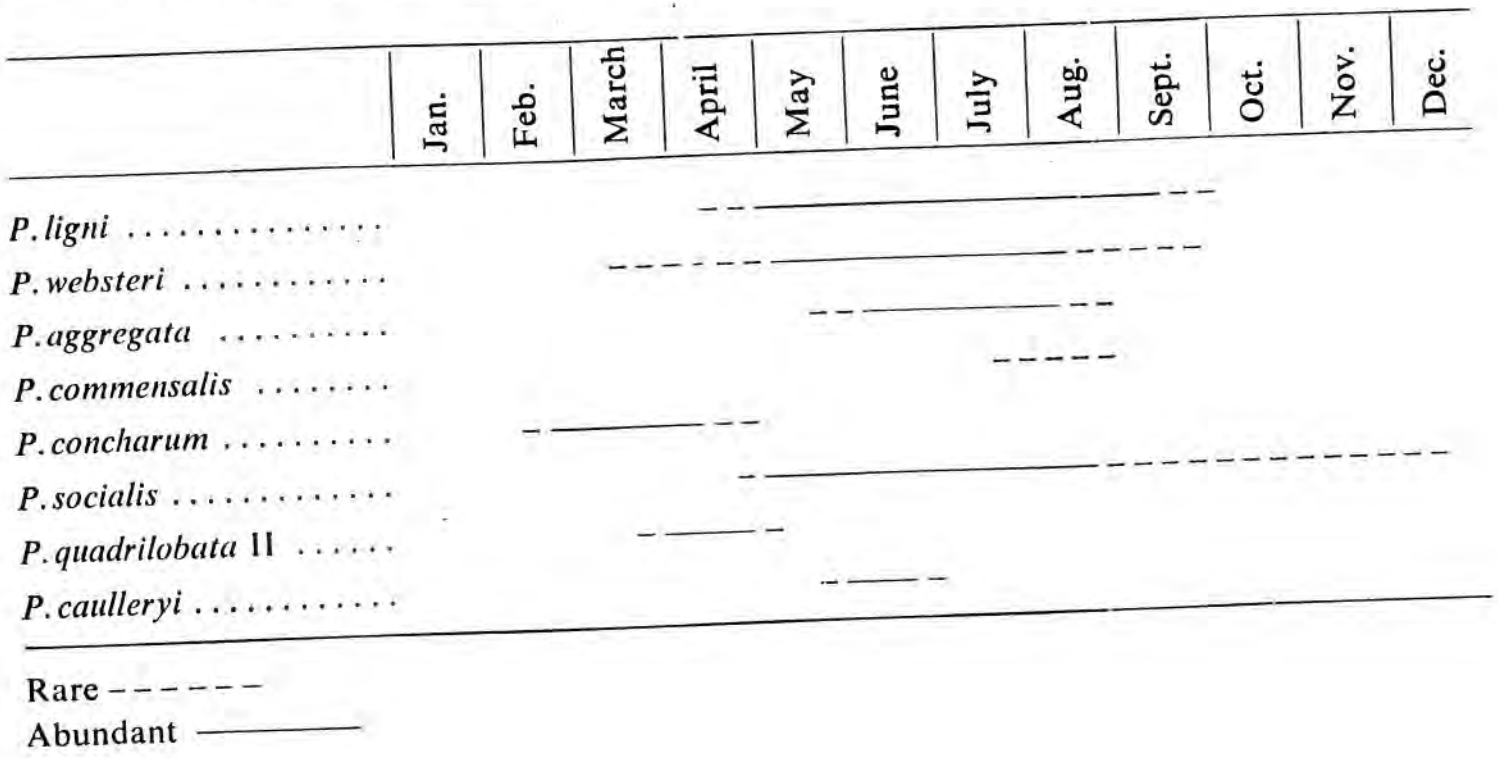


Aricidea catherinae

DENSITY OF BENTHIC INFAUNA

- Variation in densities of dominant polychaetes is likely due to different type of life cycles and reproductive requirements.
    - Spionid polychaetes common in Massachusetts Bay produce pelagic larvae at different times of the year and the timing may vary from one year to the next, possibly because of annual variation in climate.
    - Spionid polychaetes and possibly others are polytelic, where a single individual female is able to produce multiple broods within a single season that in turn settle and produce more progeny and dense populations. The species that initiates this process first will likely be the dominant in that season.
    - Capitellid and paraonid polychaetes appear to have more stable year to year population density possibly because they have longer breeding seasons.
    - Dense assemblages of polychaetes and amphipods form tube mats (Stages I and II of Rhoads and Germano) that develop rapidly, mature, and then break up.

Seasonal Occurrence of *Polydora* Larvae in Maine Waters, 1966-1968 (after Blake, 1969)



NEARFIELD FAUNAL ASSEMBLAGES 1992-1995

- **Nearfield infaunal communities consist of three different assemblages present in some form year to year.**
    - **Assemblage A includes NF Stations 4 and 17, and sometimes 2, 13, and 23. This assemblage typically contains syllid polychaetes (*Exogone*), *Corophium* amphipods, and sometimes bivalve molluscs and enchytraeid oligochaetes. The assemblage inhabits sandy sediments.**
    - **Assemblage B is usually a spionid polychaete assemblage (*Spio, Prionospio, Polydora*), with the composition variable from year to year. The sediments tend to be mixed sands and silts. In different years these stations may include cirratulids (*Tharyx* and *Aphelochaeta*) and capitellids (*Mediomastus*). At those times the sediments are more silty.**
    - **Assemblage C is a capitellid-dominated (*Mediomastus*) assemblage. The sediments are typically muddy (>70% silt + clay). In different years, spionids and paraonids may make up significant portions of the fauna.**

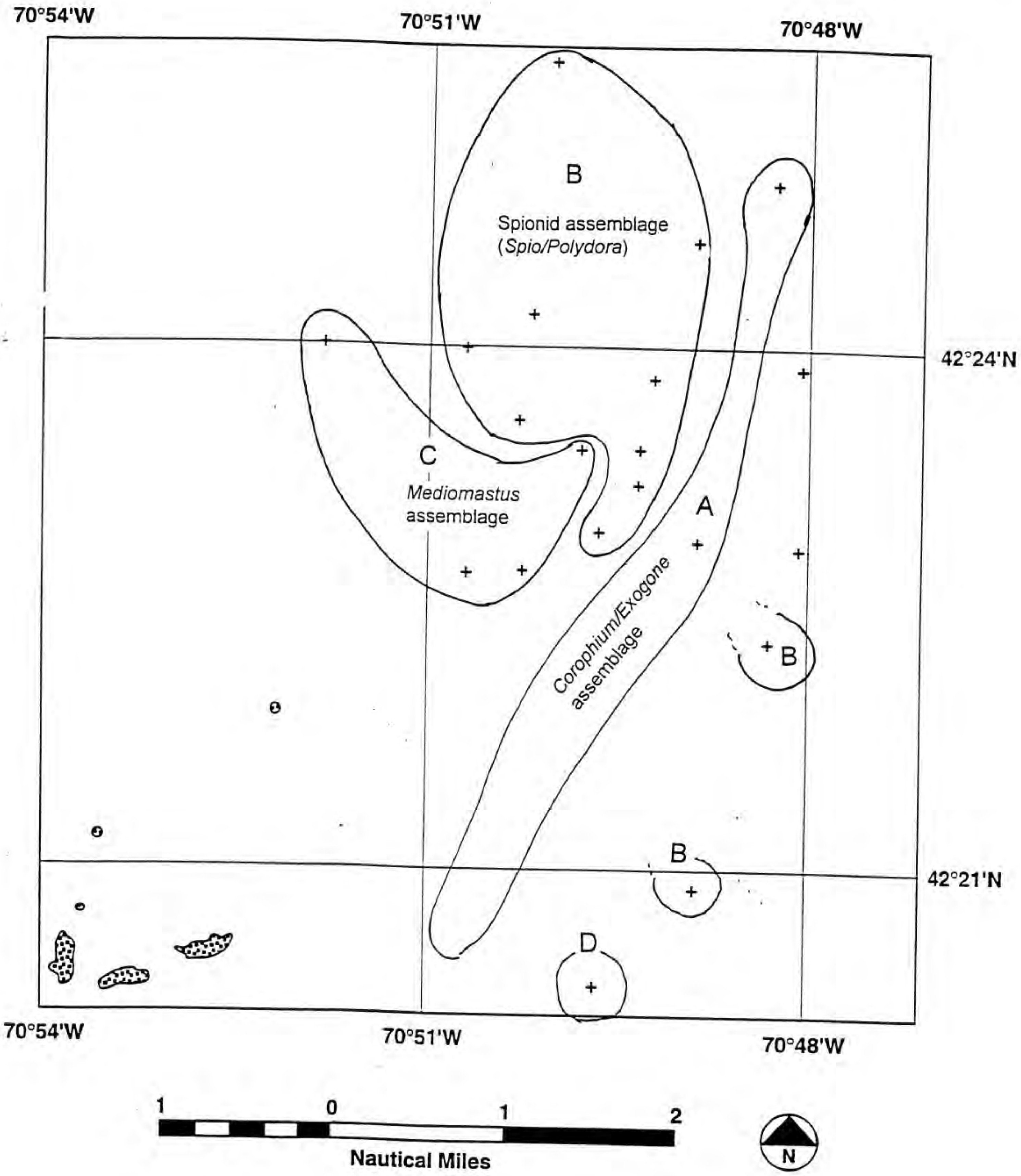


Fig. 25 Nearfield Faunal Assemblages: 1992

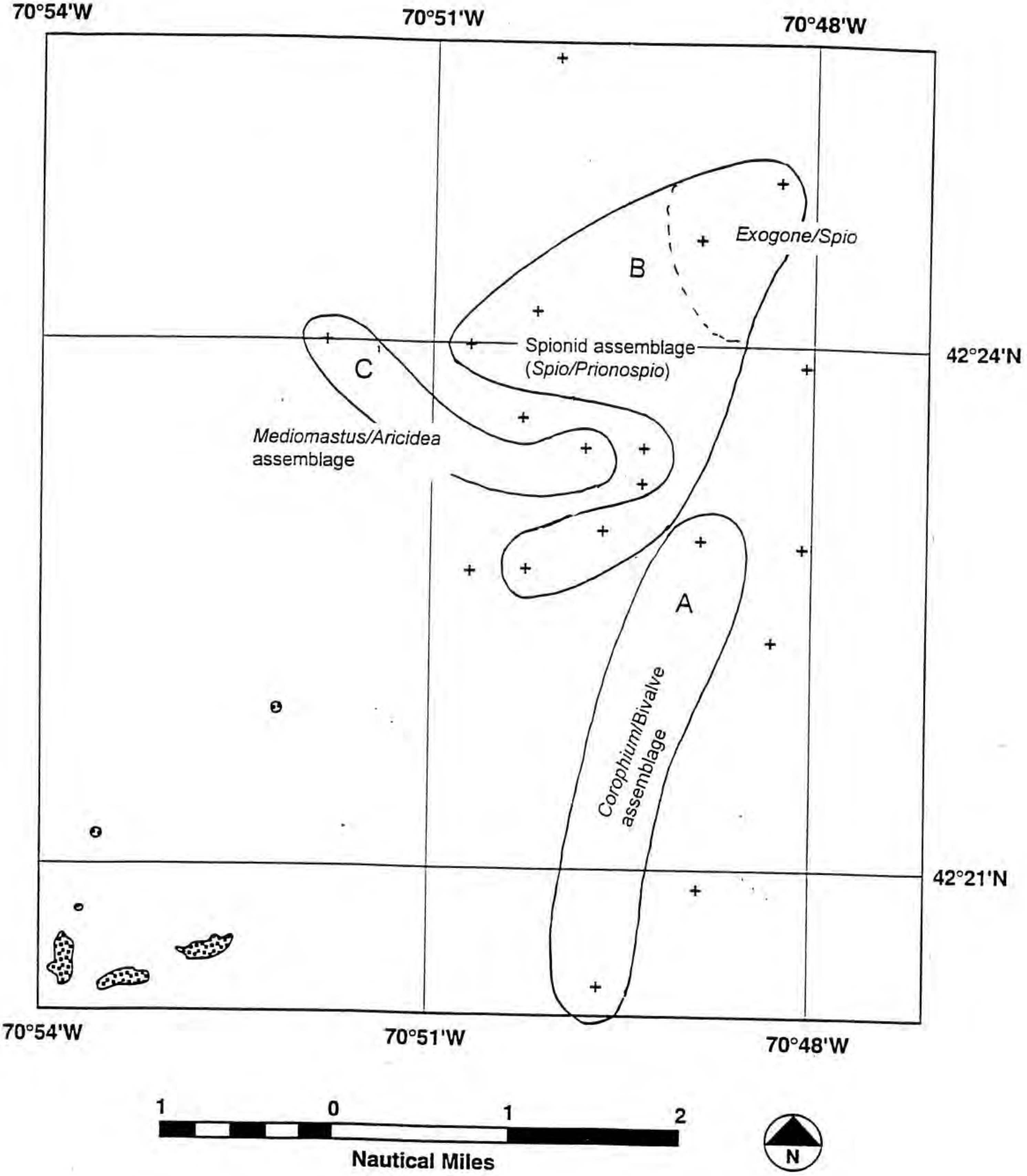


Fig. 26 Nearfield Faunal Assemblages: 1993

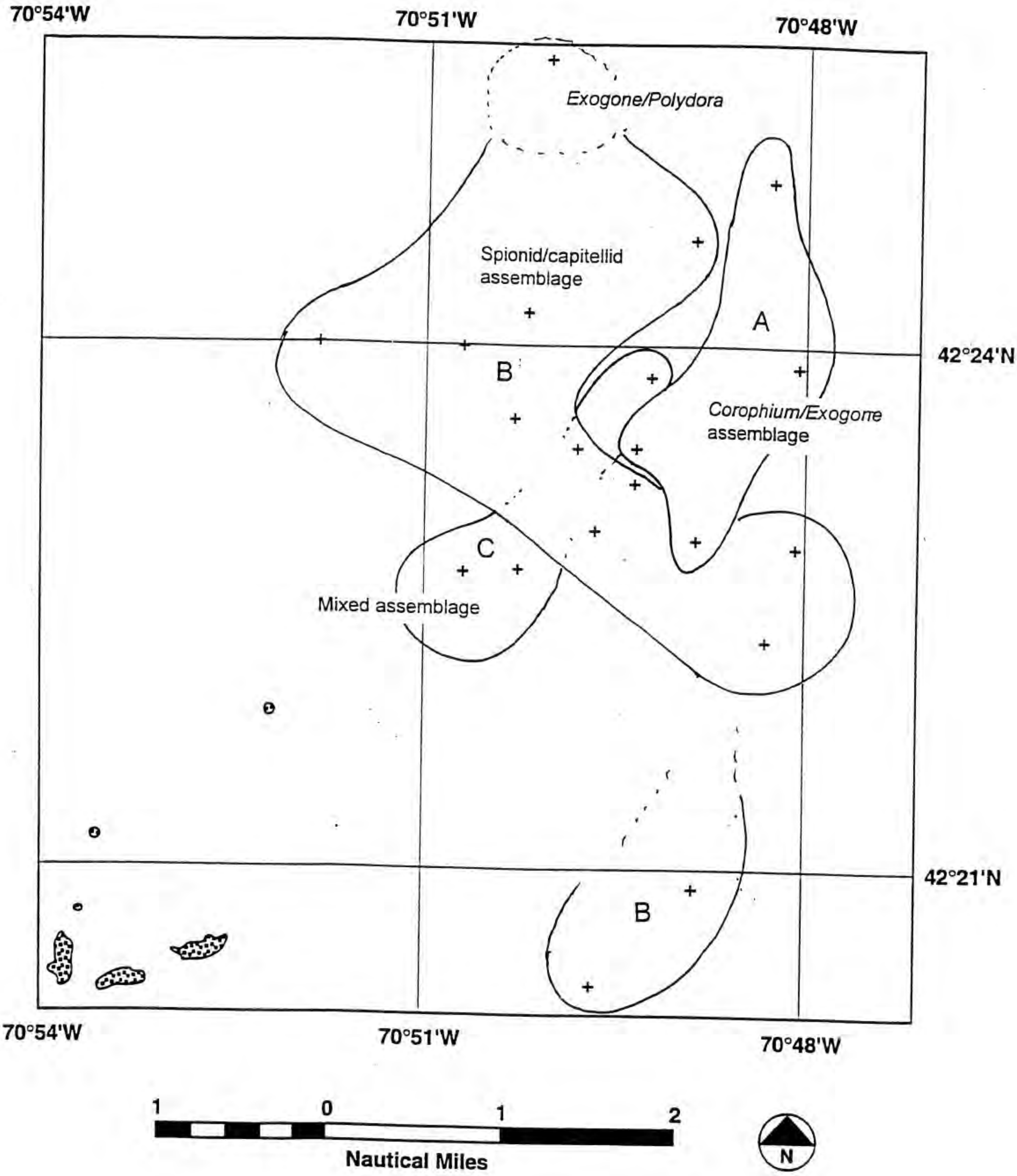


Fig. 27. Nearfield Faunal Assemblages: 1994

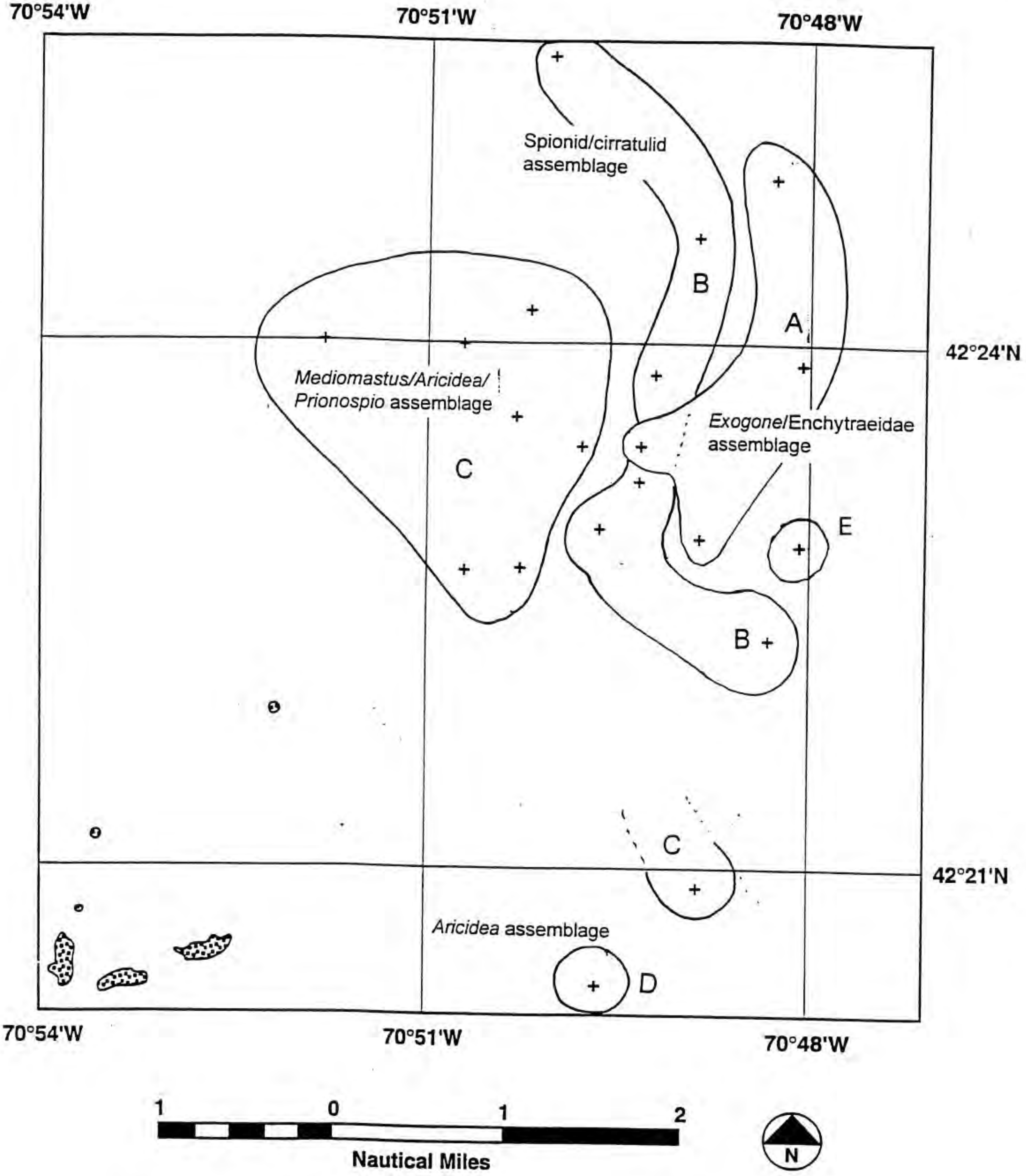


Fig. 28. Nearfield Faunal Assemblages: 1995

APPENDIX C-7

Brian Howes
WHOI

Monitoring of Rates of Carbon, Nitrogen and Oxygen Cycling in Sediment Systems and the Prediction and Analysis of Ecological Change

Brian L. Howes and David R. Schlezinger
Woods Hole Oceanographic Institution

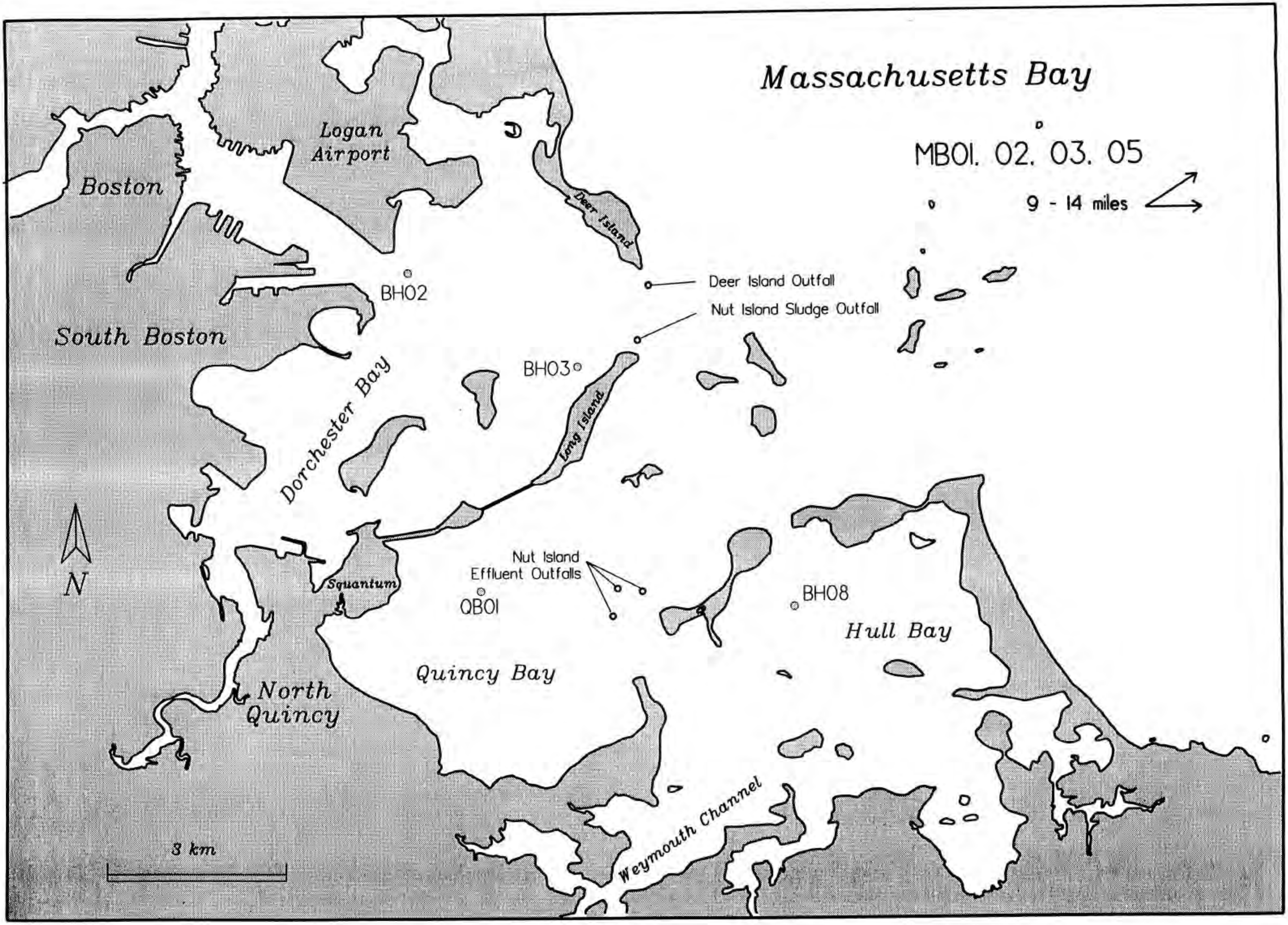
Focus

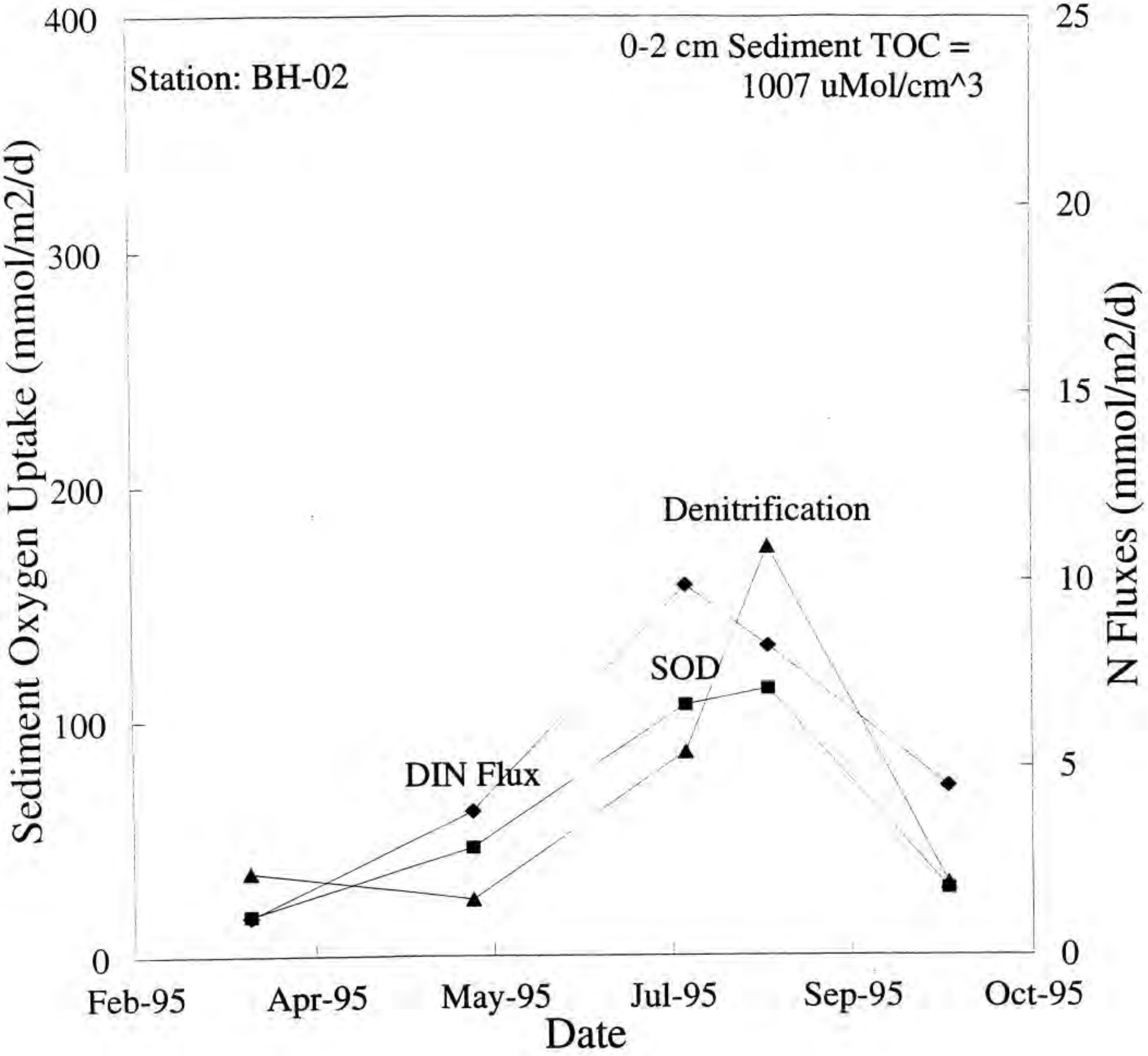
Sediment systems as:

1) Indicators of change:
    a) RPD depth
    b) transformation rates as quantitative indicators of loading
    c) temporal integrator (dampening short-term variation)
    d) process-level integrator

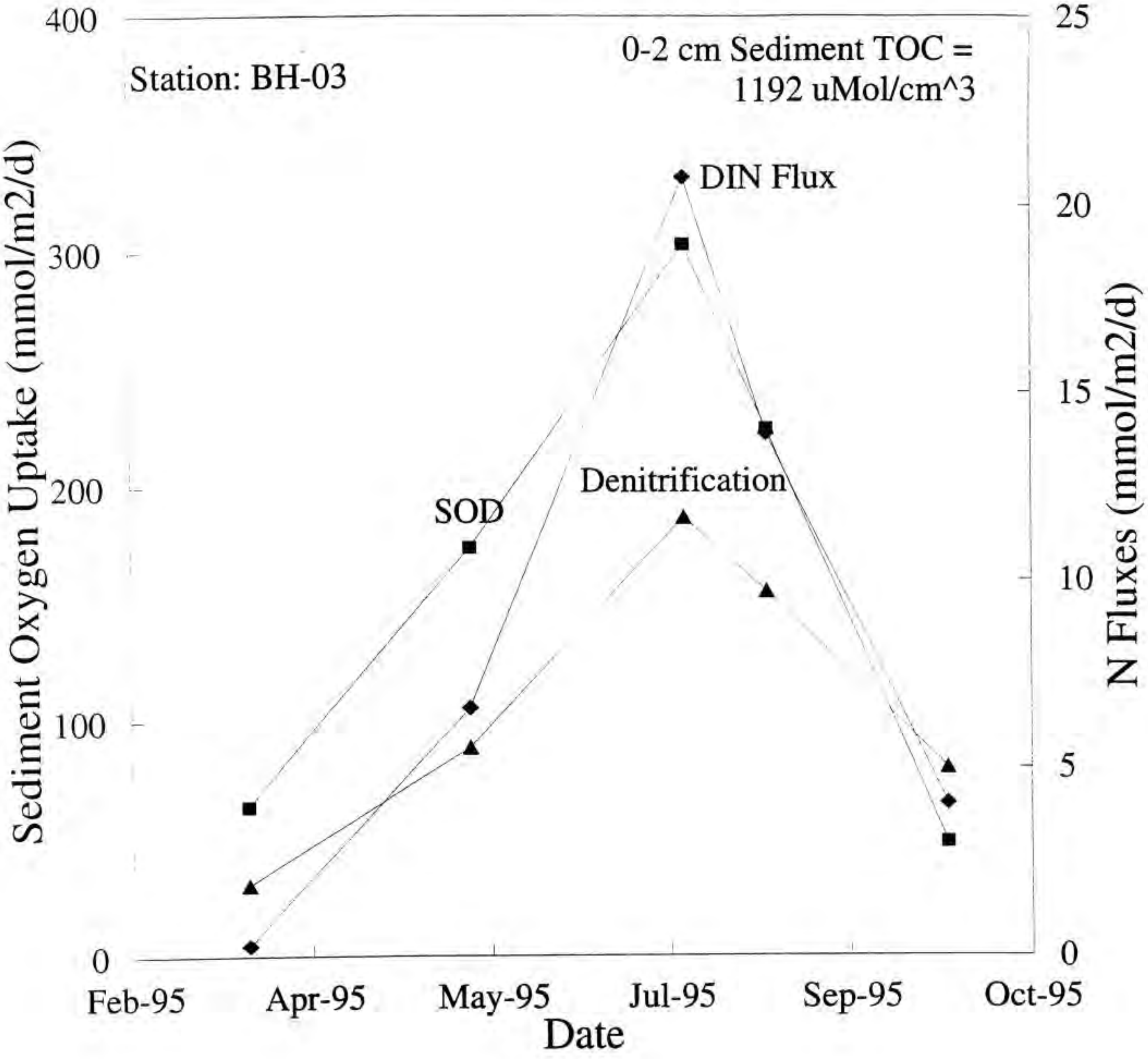
2) Key component in bottom water oxygen depletion: therefore can be used in prediction of potential change

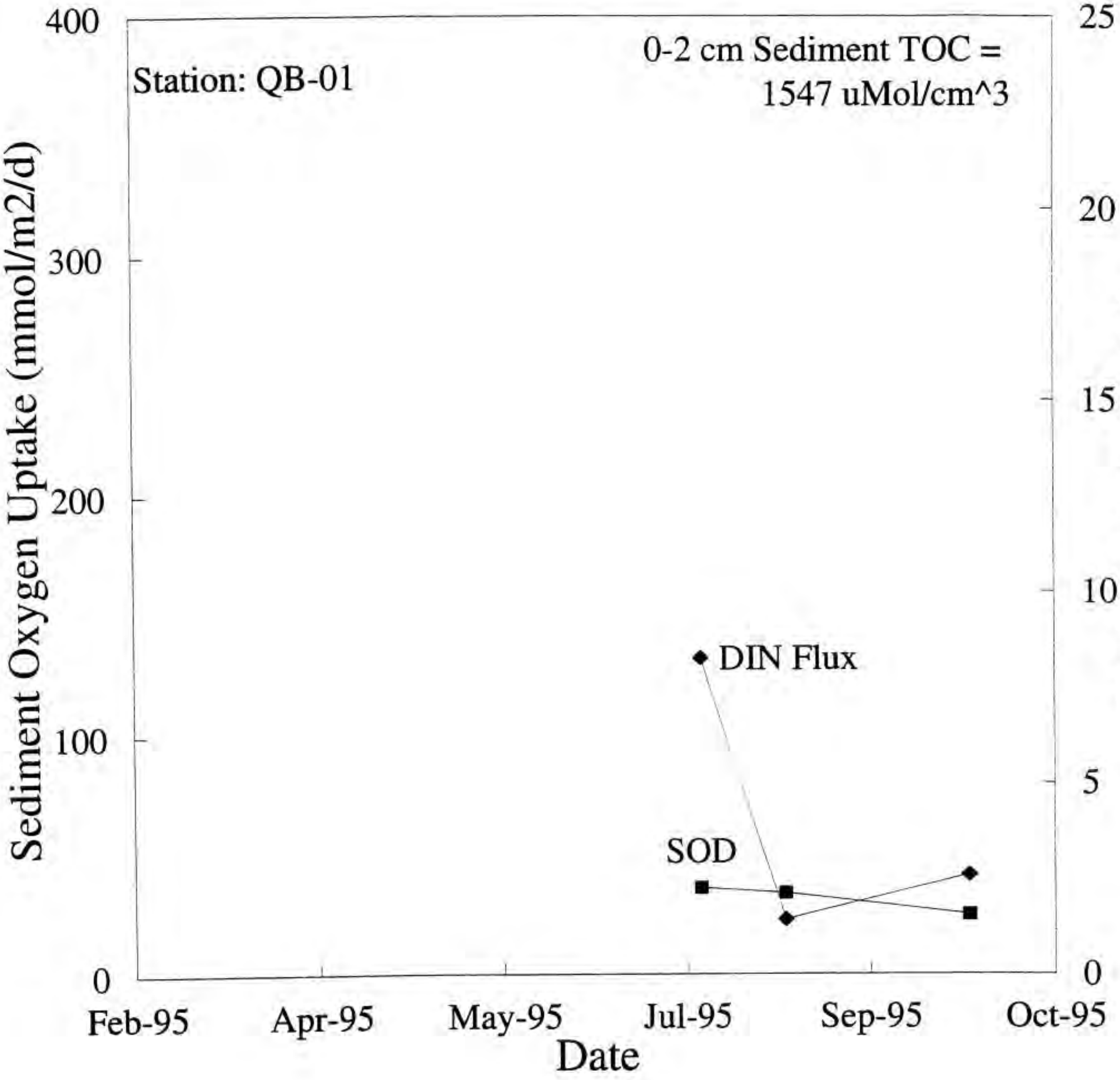
3) Process-level input to ecological models:
    a) inter-system comparisons
    b) non-linear responses to loading rates
    c) initial method for addressing oxygen ventilation


Massachusetts Bay
MBOI. 02. 03. 05
9 - 14 miles
Logan Airport
Boston
Deer Island
BH02
Deer Island Outfall
Nut Island Sludge Outfall
South Boston
BH03
Dorchester Bay
Long Island
N
Nut Island Effluent Outfalls
Squantum
QBOI
BH08
Hull Bay
Quincy Bay
North Quincy
Weymouth Channel
3 km

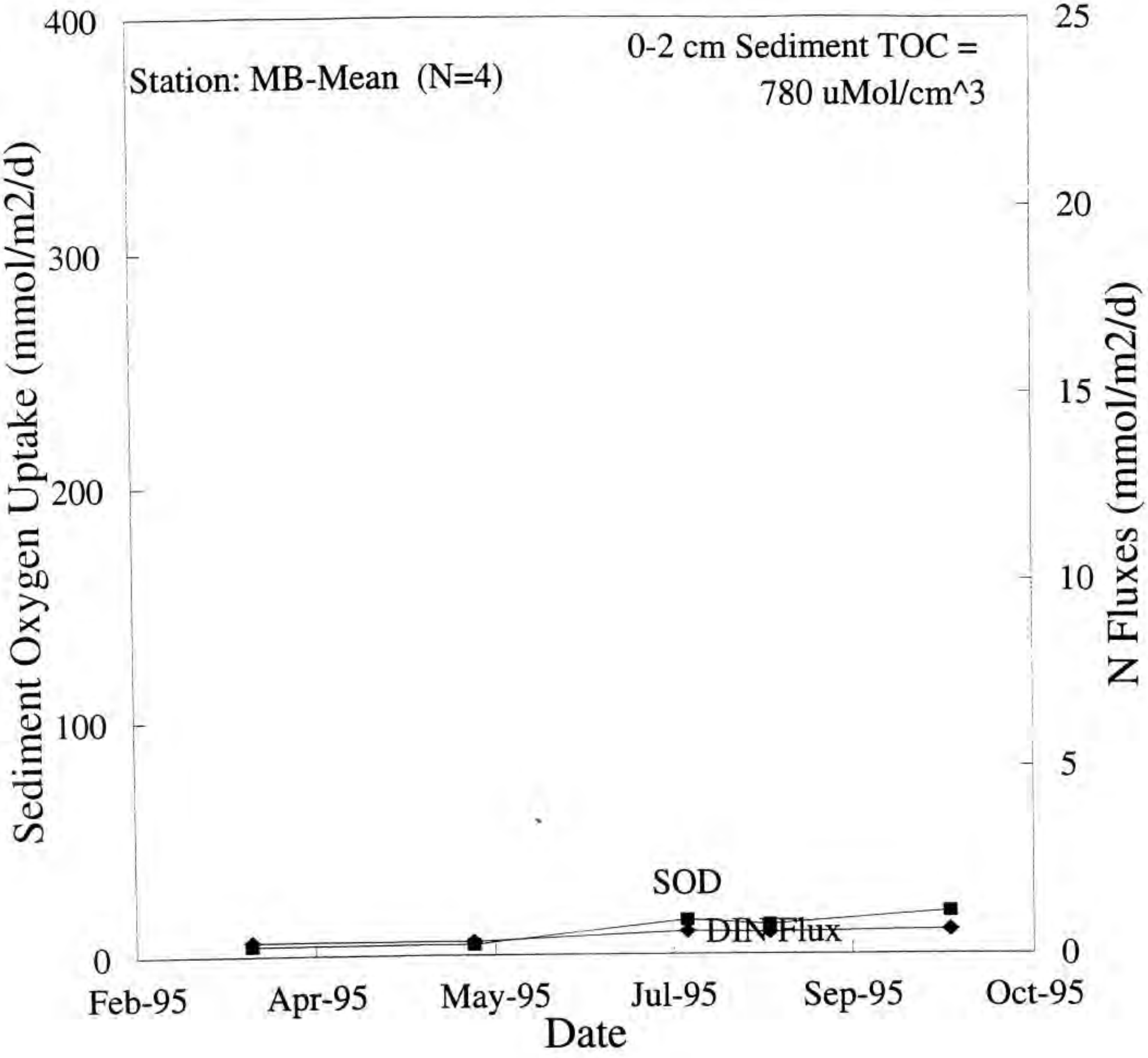


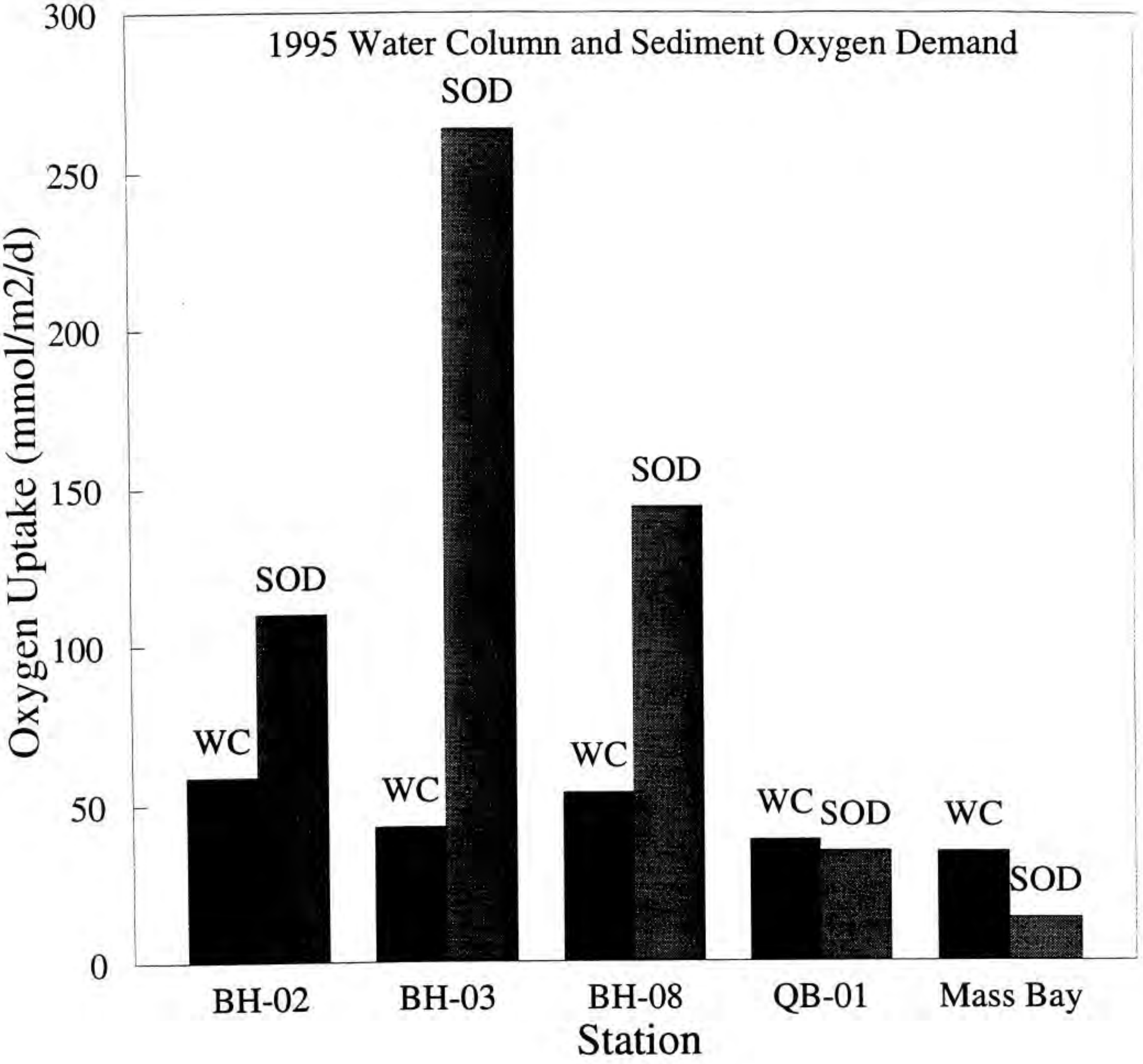
Station: BH-02
0-2 cm Sediment TOC = 1007 uMol/cm^3
Sediment Oxygen Uptake (mmol/m2/d)
N Fluxes (mmol/m2/d)
400
300
200
100
0
25
20
15
10
5
0
Denitrification
SOD
DIN Flux
Feb-95
Apr-95
May-95
Jul-95
Sep-95
Oct-95
Date

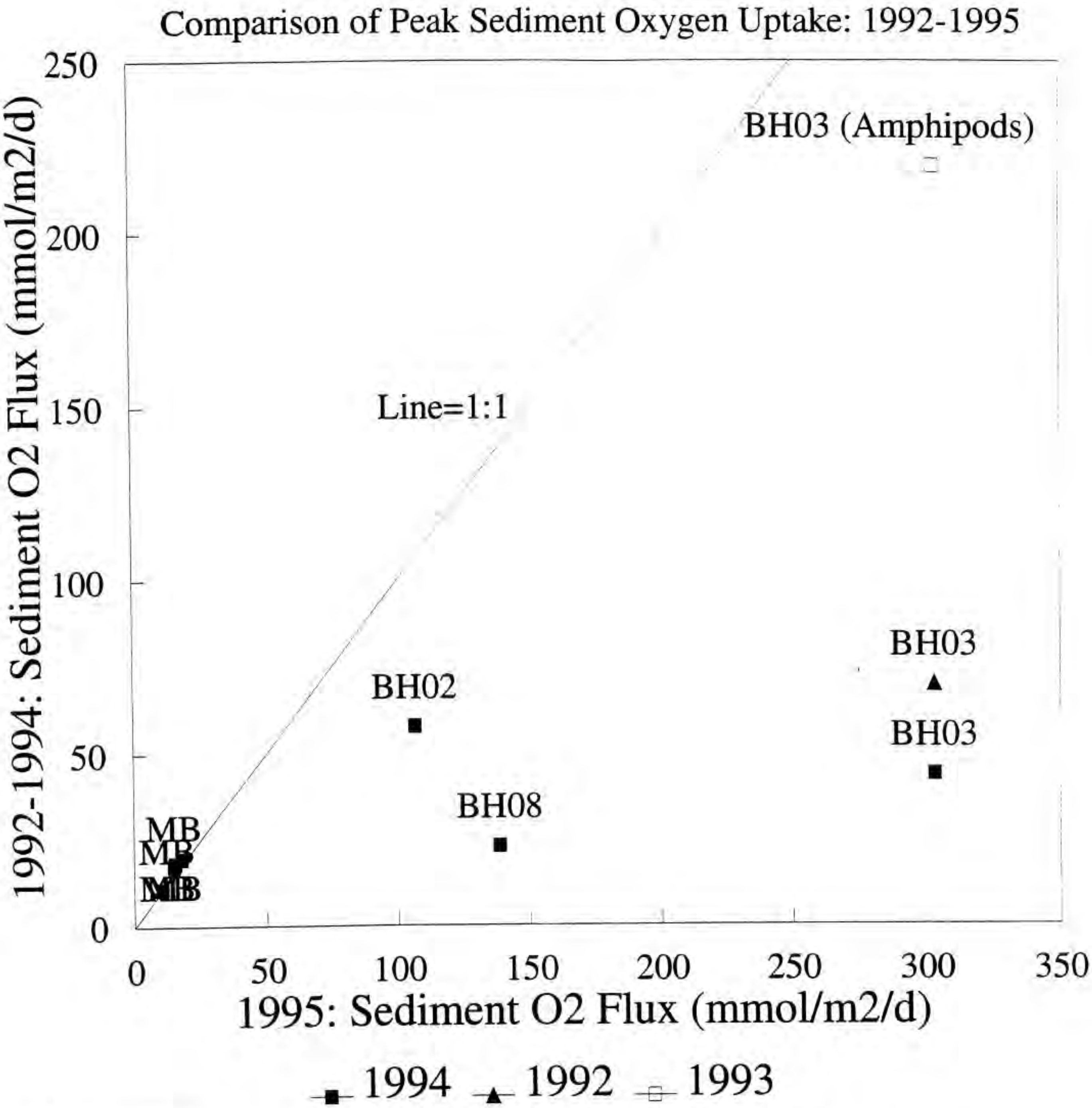

400
300
200
100
0
25
20
15
10
5
0
Station: BH-03
0-2 cm Sediment TOC =
1192 uMol/cm^3
DIN Flux
SOD
Denitrification
Sediment Oxygen Uptake (mmol/m2/d)
N Fluxes (mmol/m2/d)
Feb-95
Apr-95
May-95
Jul-95
Sep-95
Oct-95
Date



Station: QB-01
0-2 cm Sediment TOC = 1547 uMol/cm^3
Sediment Oxygen Uptake (mmol/m2/d)
N Fluxes (mmol/m2/d)
DIN Flux
SOD
400
300
200
100
0
25
20
15
10
5
0
Feb-95
Apr-95
May-95
Jul-95
Sep-95
Oct-95
Date

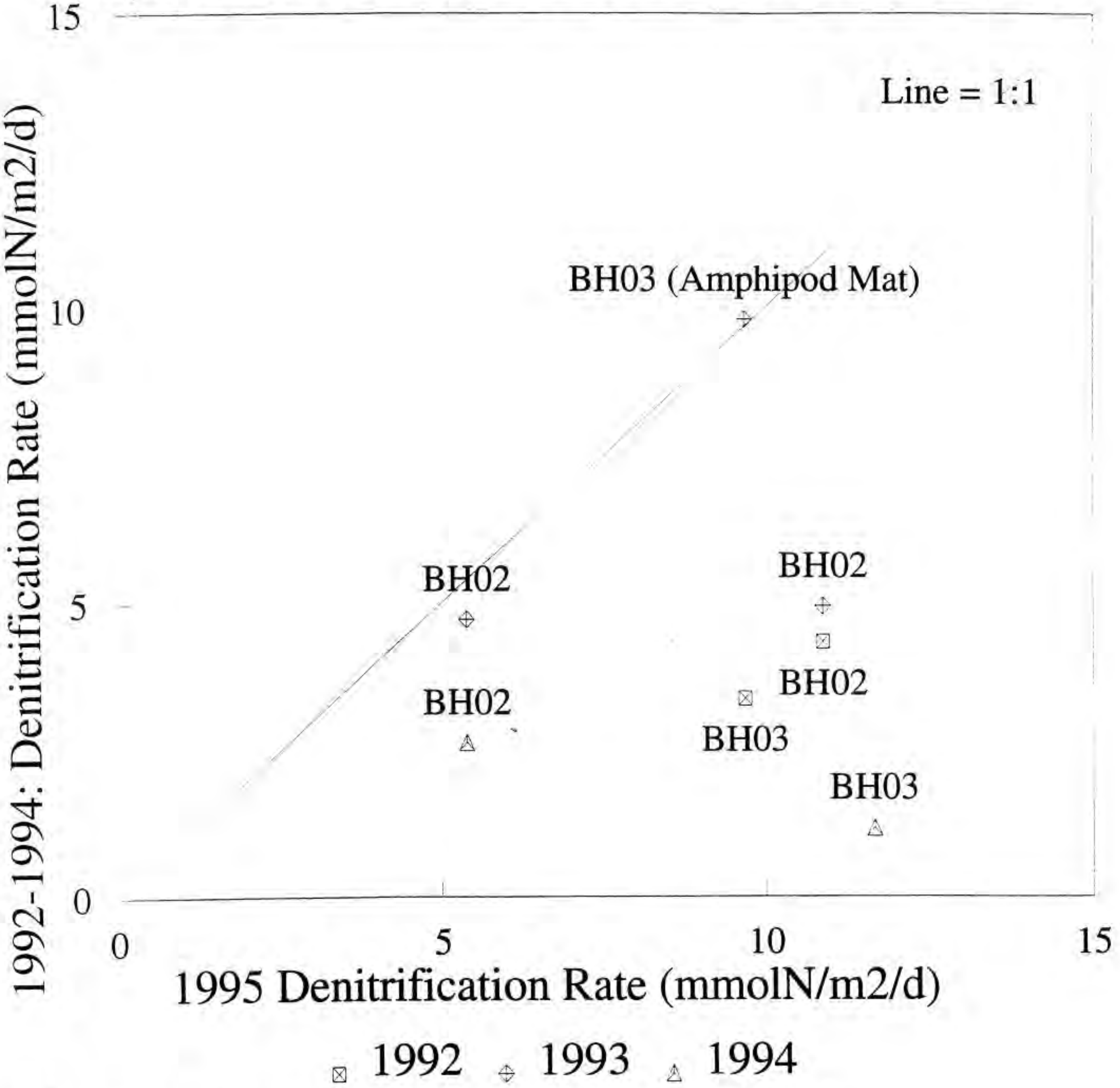

Station: MB-Mean (N=4)
0-2 cm Sediment TOC =
780 uMol/cm^3
Sediment Oxygen Uptake (mmol/m2/d)
400
300
200
100
0
N Fluxes (mmol/m2/d)
25
20
15
10
5
0
SOD
DIN Flux
Feb-95
Apr-95
May-95
Jul-95
Sep-95
Oct-95
Date


1995 Water Column and Sediment Oxygen Demand
Oxygen Uptake (mmol/m2/d)
300
250
200
150
100
50
0
WC
SOD
WC
SOD
WC
SOD
WC
SOD
WC
SOD
BH-02
BH-03
BH-08
QB-01
Mass Bay
Station

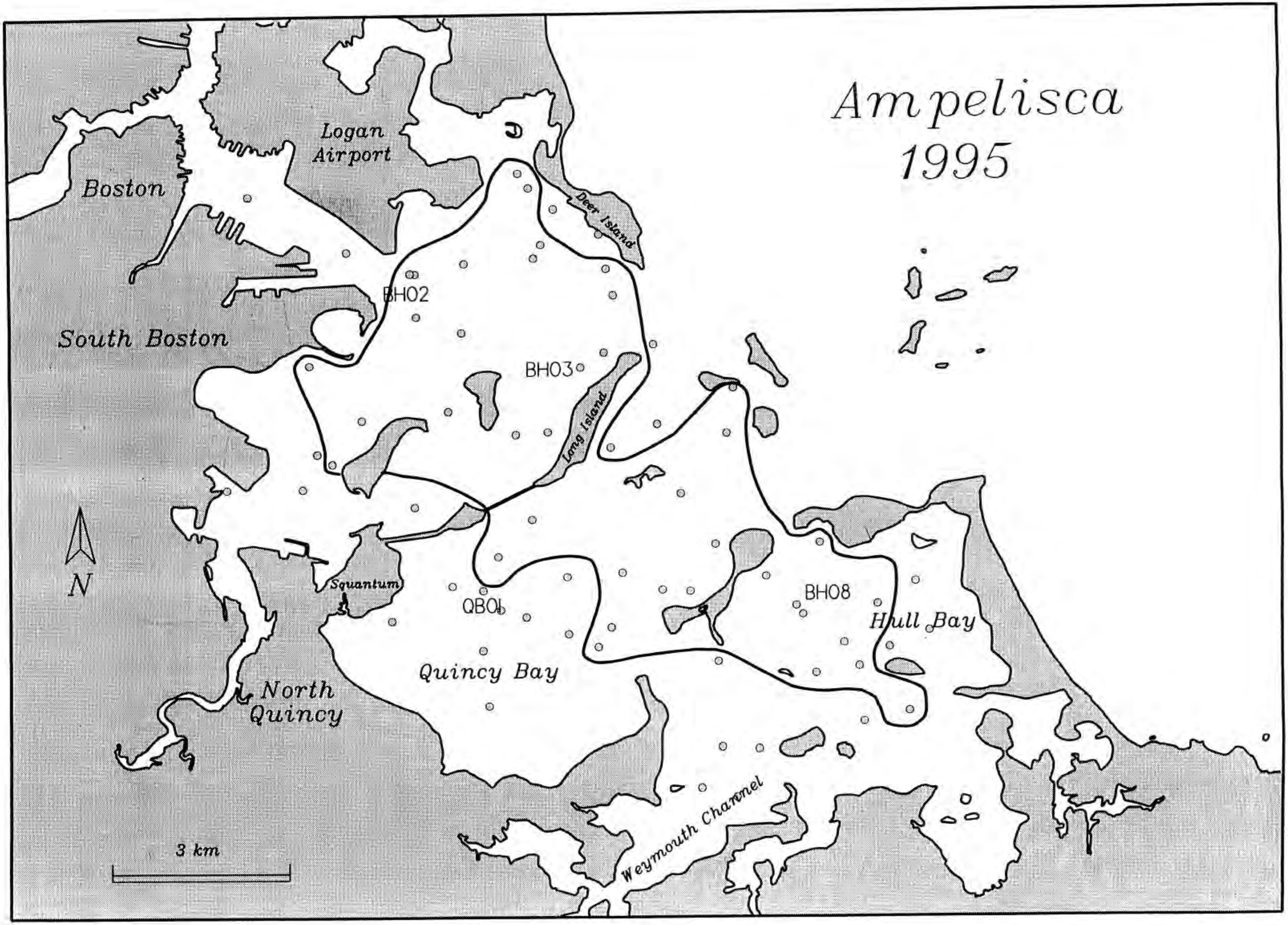


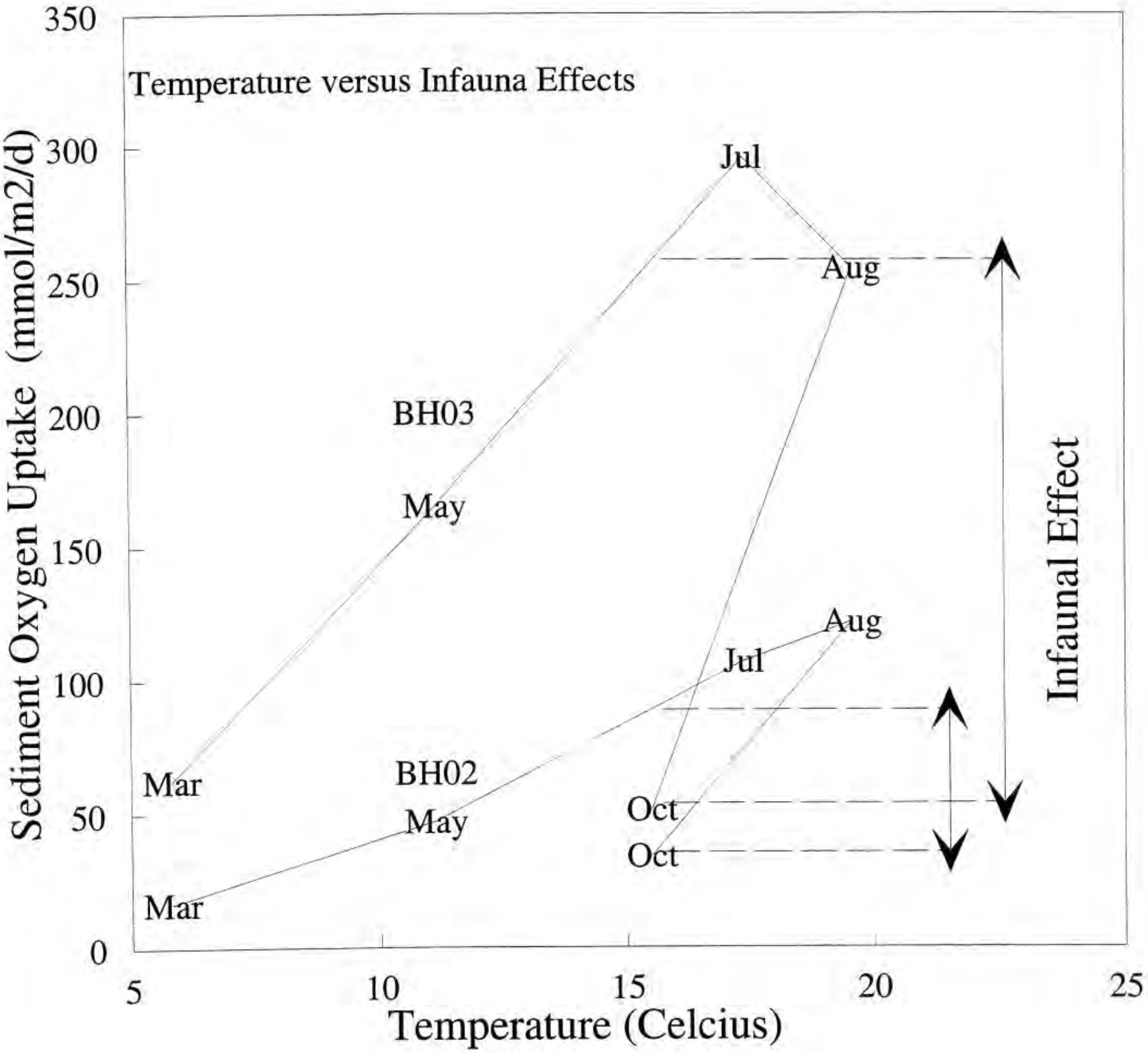
Maximum rates are typically found in July and August
1992-1994 data from Giblin et al. May 1995; 1995 from current study.

Comparison of Peak Denitrification Rates: 1992-1995

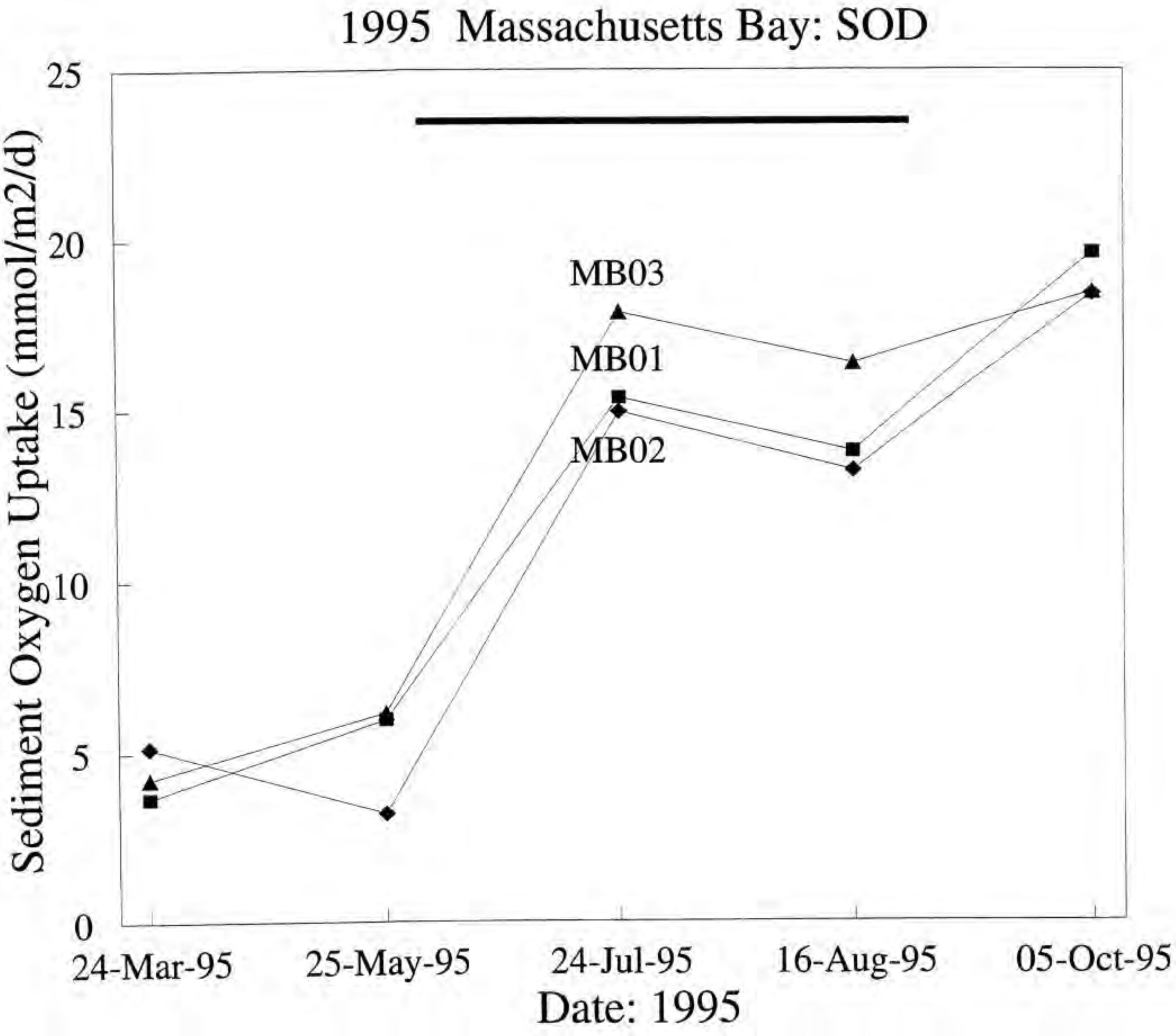


Maximum rates are typically found in July and August
1992-1994 data from Nowicki et al.; 1995 from current study.

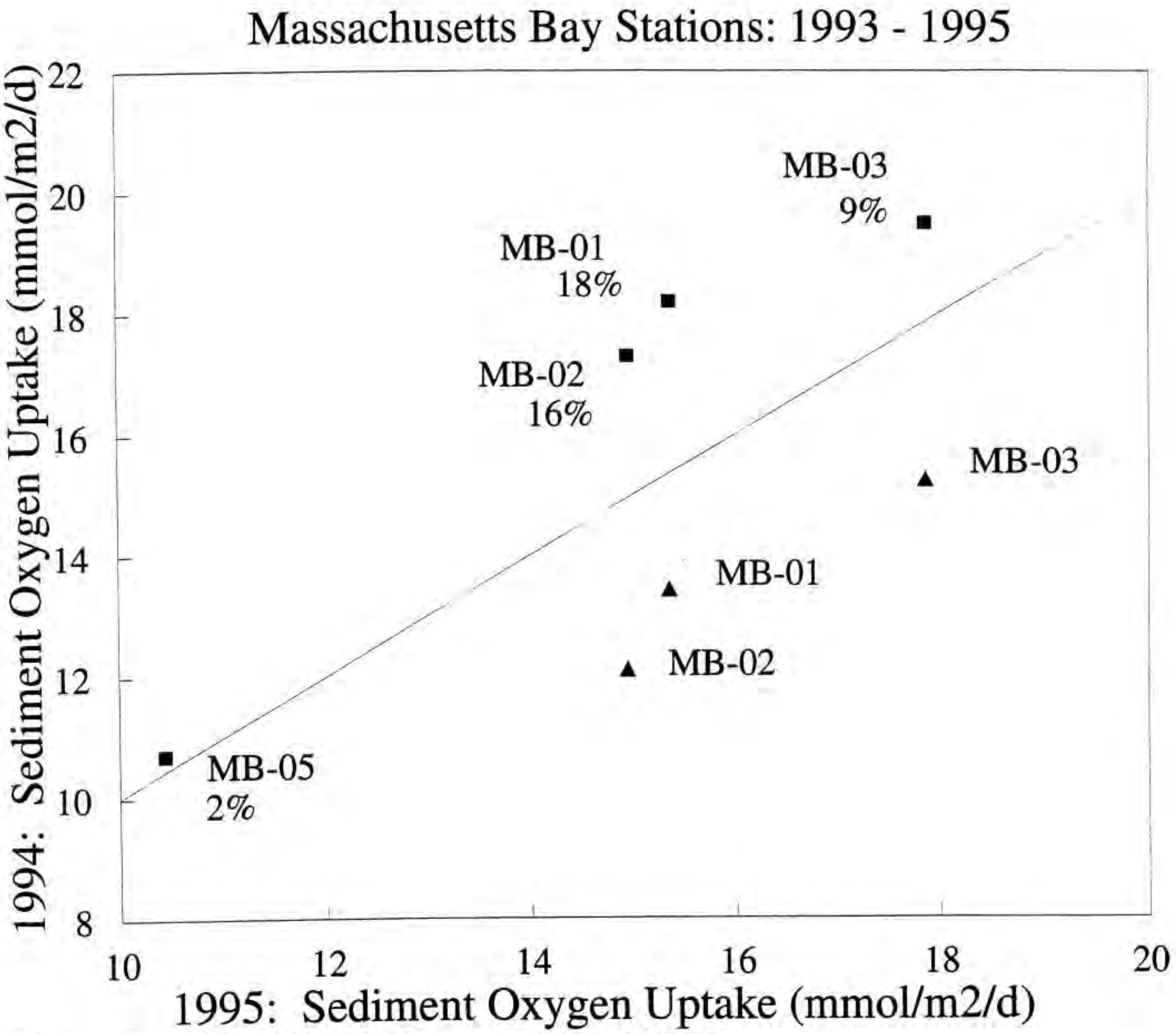

Ampelisca
1995


Temperature versus Infauna Effects
Sediment Oxygen Uptake (mmol/m2/d)
0
50
100
150
200
250
300
350
5
10
15
20
25
Temperature (Celcius)
BH03
Mar
May
Jul
Aug
Oct
BH02
Mar
May
Jul
Aug
Oct
Infaunal Effect

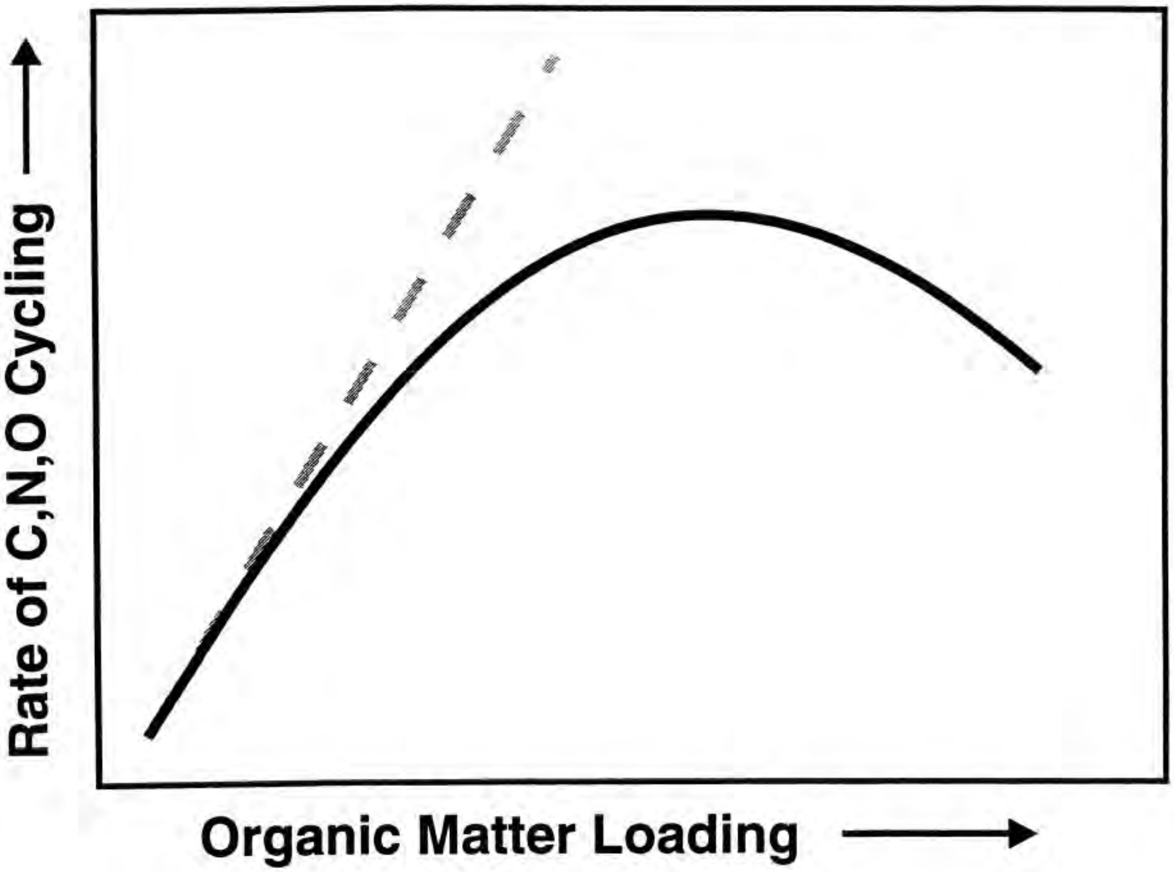
Low Organic Matter Low Animal Density	High Organic Matter Low animal Density QB
Low Organic Matter High Animal Density MB-01 MB-02 MB-03 MB-05	High Organic Matter High Animal Density BH-02 BH-03

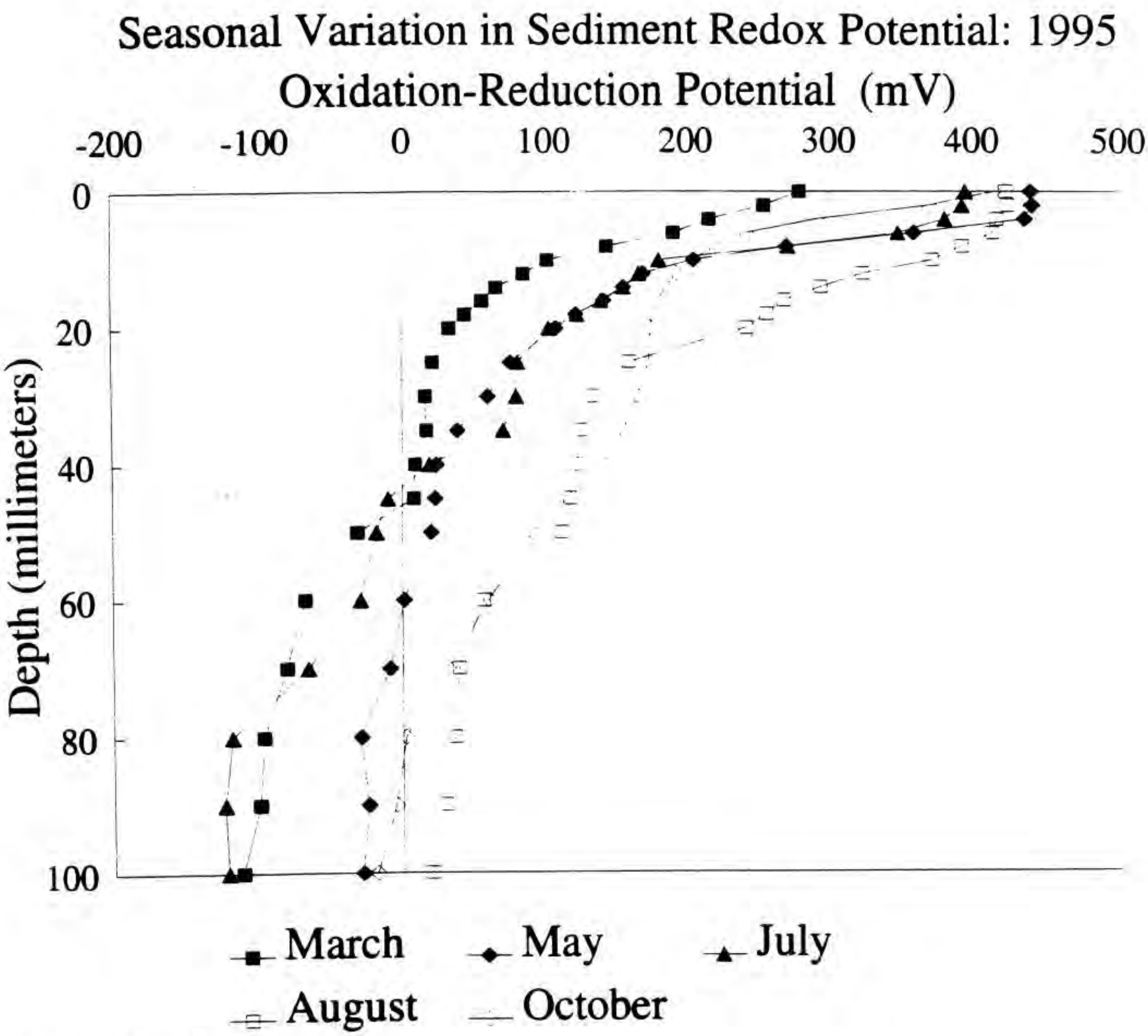


Bar represents period of stratification.
Station Means: N=4.



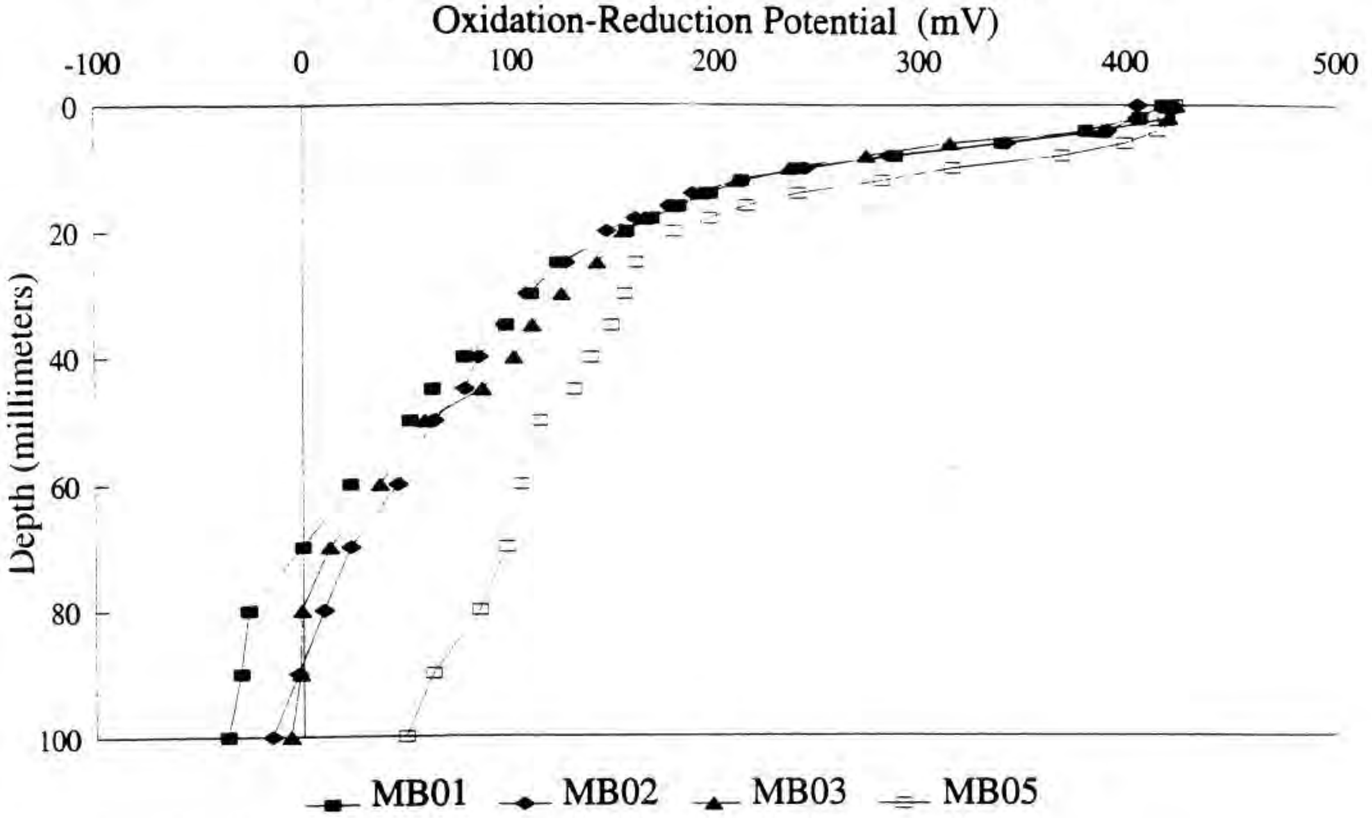
Summer rates: 1994-Giblin et al.; 1995-WHOI
Values (%) below symbols are % deviation from 1995.


Rate of C,N,O Cycling
Organic Matter Loading

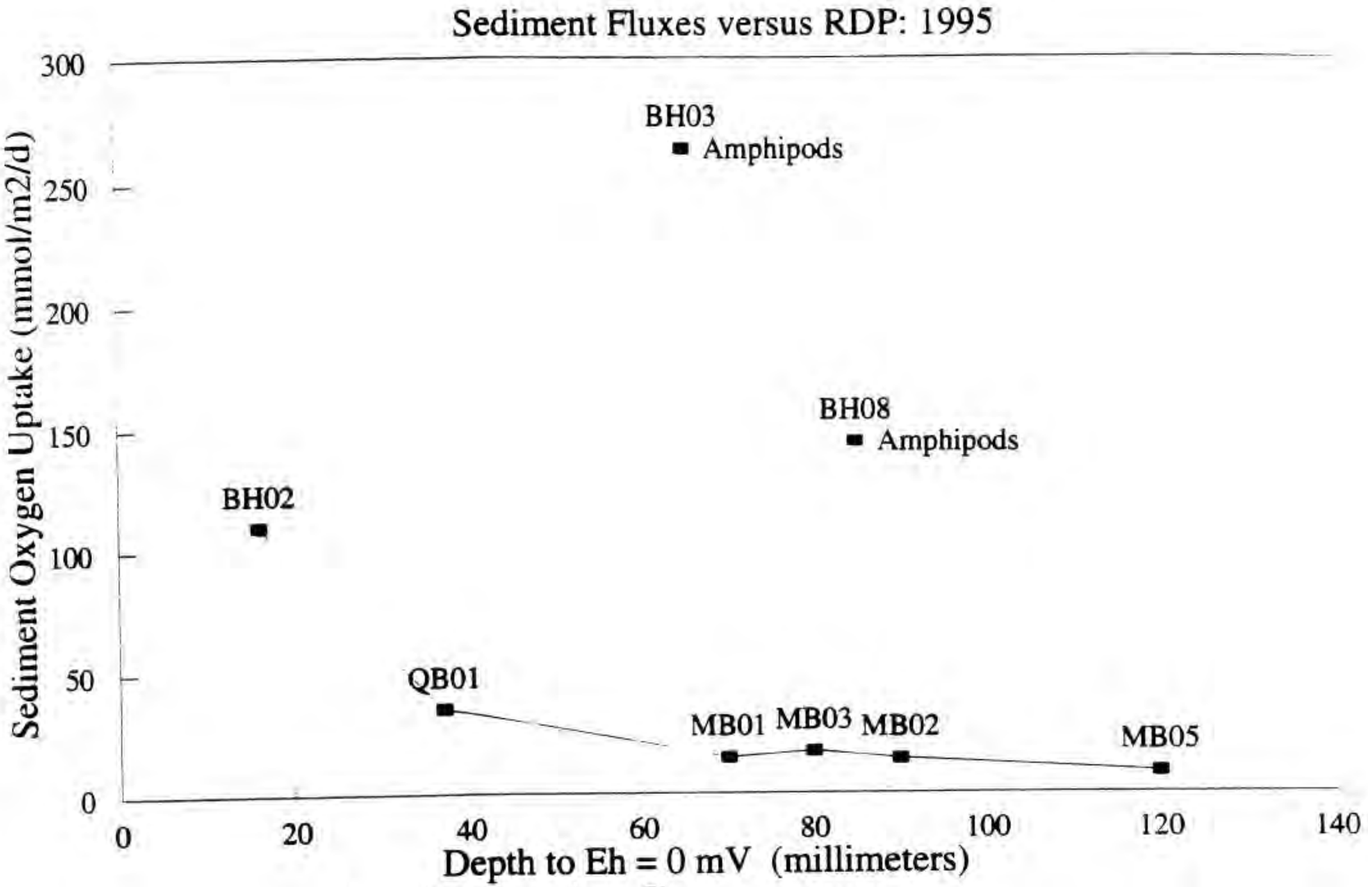


Station MB01

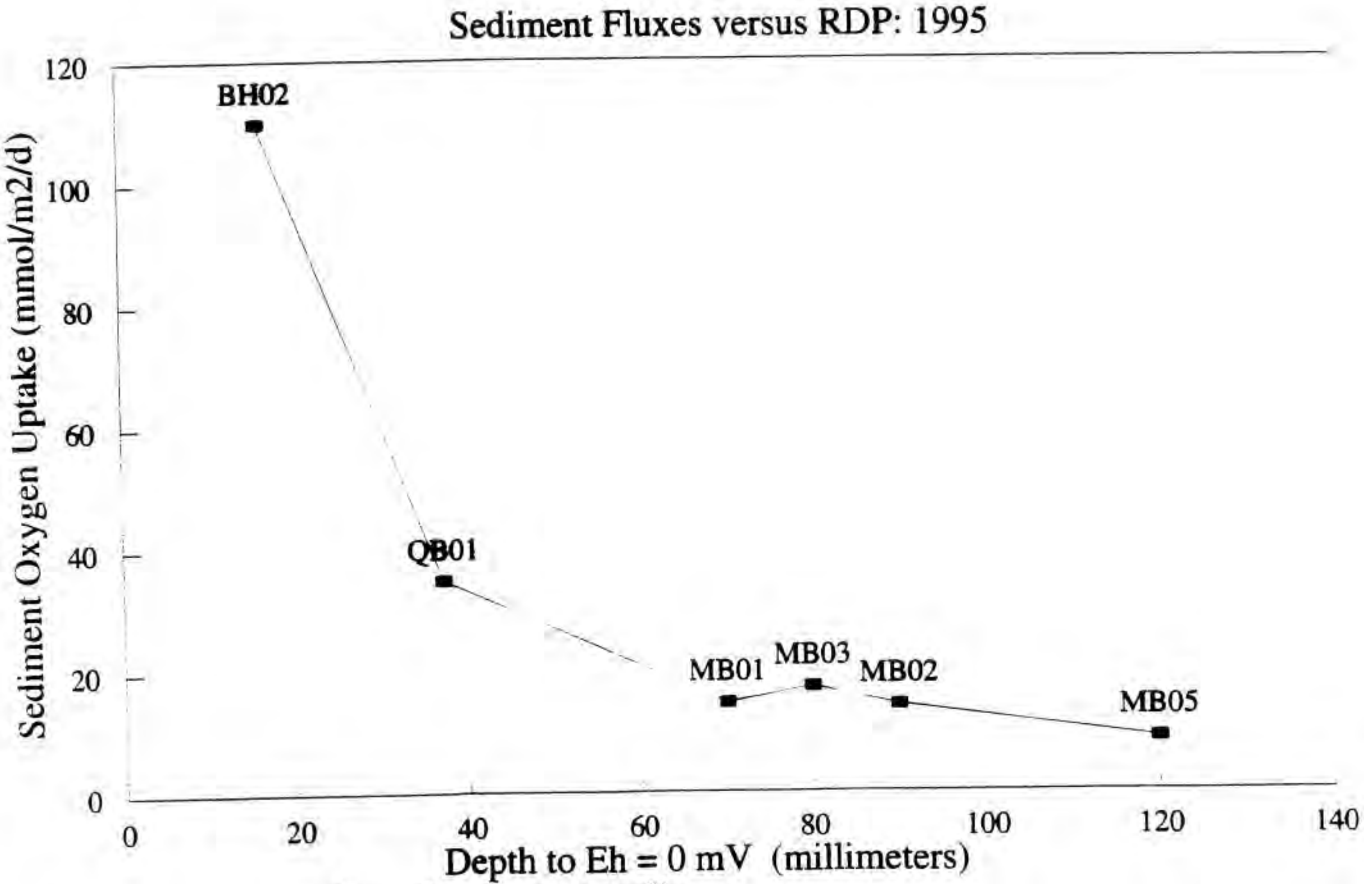
Seasonal Variation in Sediment Redox Potential: 1995



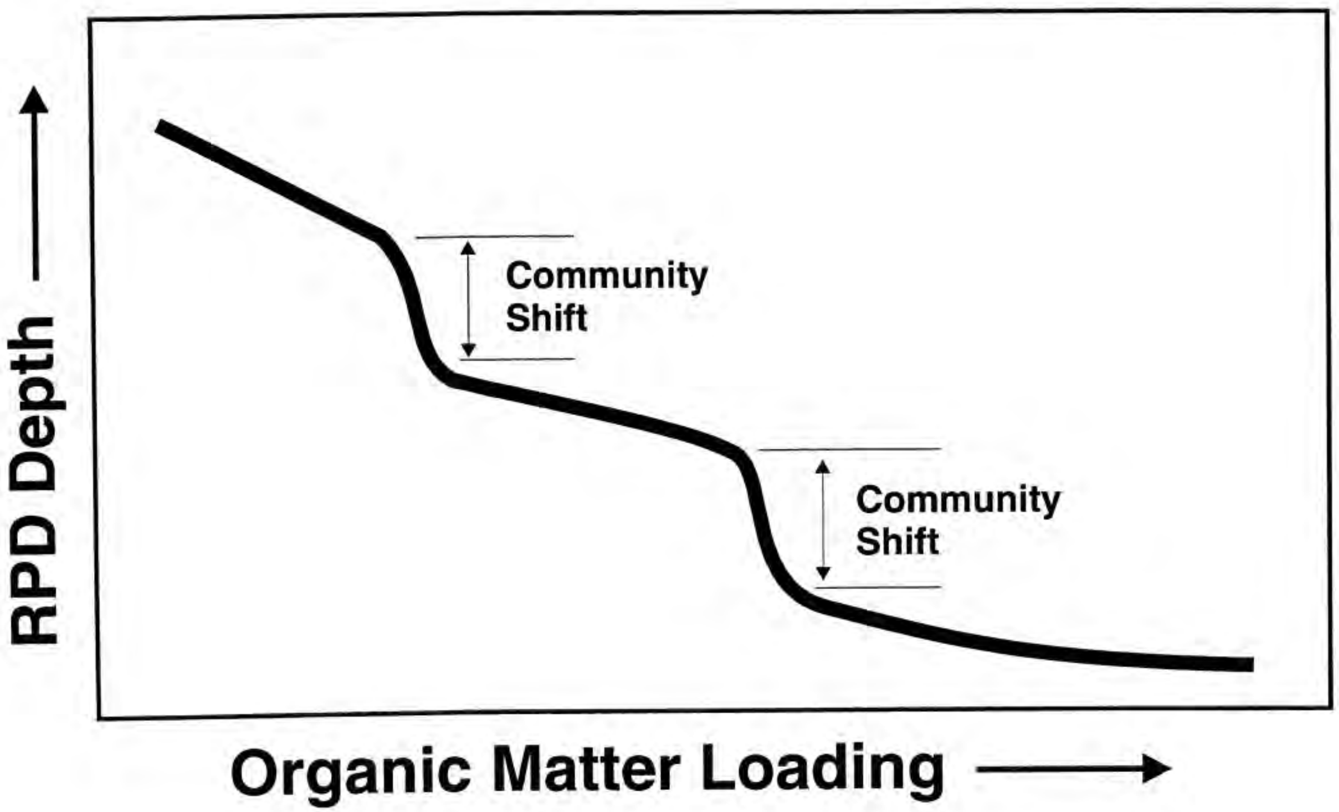
Means: June, July, August, October.



RDP is summer average from micro-electrode profiles.



RDP is summer average from micro-electrode profiles.


RPD Depth
Community Shift
Community Shift
Organic Matter Loading

APPENDIX C-8

Barbara Hecker

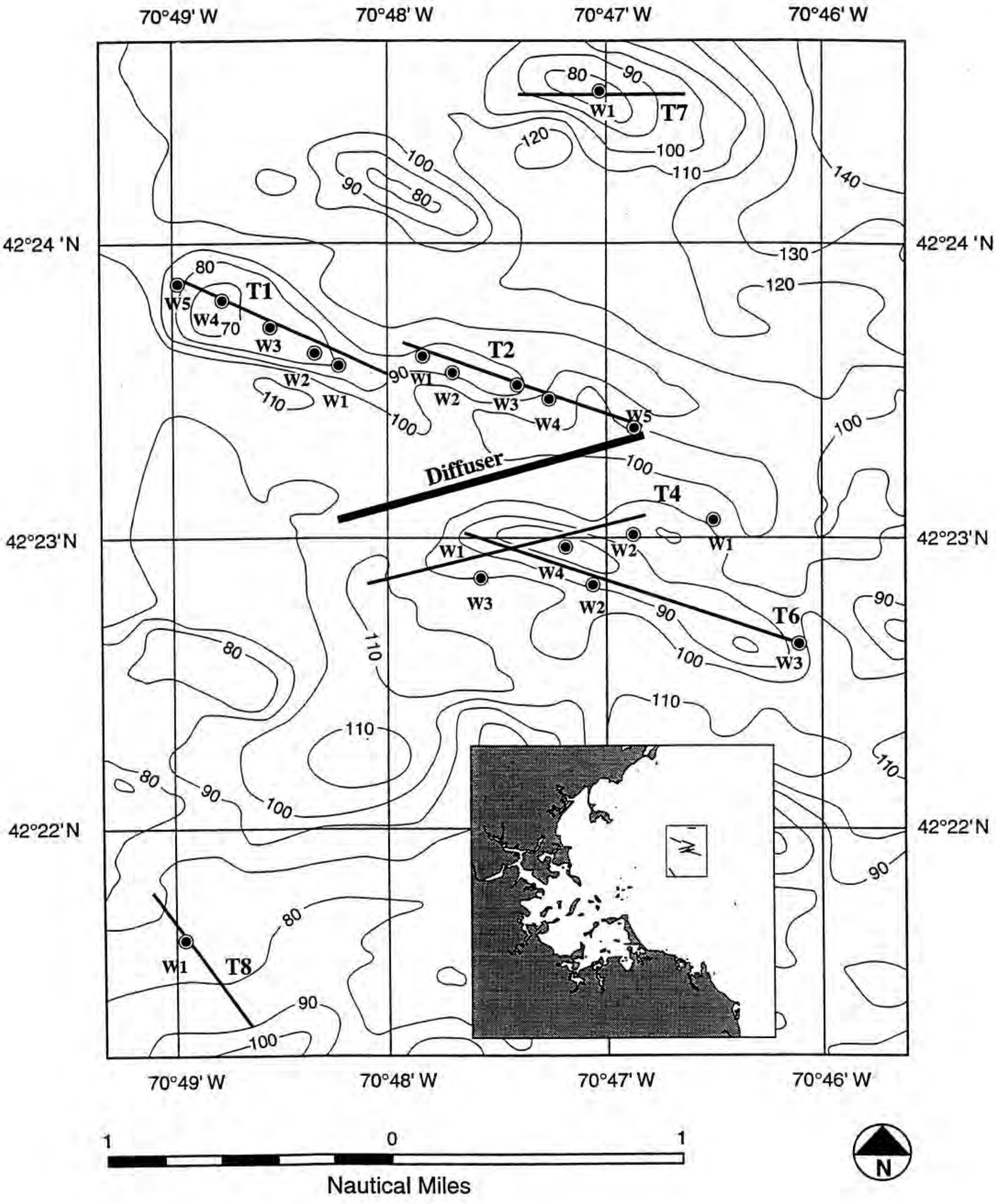

70°49' W
70°48' W
70°47' W
70°46' W
42°24 'N
42°23'N
42°22'N
T1
T2
T4
T6
T7
T8
W1
W2
W3
W4
W5
Diffuser
70
80
90
100
110
120
130
140
1
0
1
Nautical Miles
N

Table . Photographic coverage at locations surveyed during the 1995 Nearfield Hardbottom Video Survey.

Transect	Waypoint	Excursion	Location on drumlin	Depth (ft)	(m)	Video	Stills	Number of useable stills
1	1	1	Flank	84	25	x	x	2
	2	1	Flank	81	25	x	x	5
		2	Upper Flank	74	22	x		
	3	1	Top	72	22	x	x	9
	4	1	Top	70	21	x	x	5
	5	1	Flank	83	25	x	x	6
2	1	1	Upper Flank	87	26	x		
		2	Upper Flank	87	26	x	x	3
		3	Top	85	26	x	x	11
	2	1	Upper Flank	90	27		x	4
		2	Flank	90	27	x	x	3
	3	1	Upper Flank	95	29	x	x	5
	4	1	Lower Flank	105	32	x		
	5	1	Lower Flank	112	34	x	x	11
		2	Lower Flank	112	34	x	x	7
		3	Lower Flank	112	34	x		
		diffuser	Low	112	34	x		
4	1	1	Lower Flank	105	32	x	x	5
	2	1	Upper Flank	86	26	x	x	6
		2	Upper Flank	85	26	x	x	7
	3	1	Flank	103	31	x	x	5
4&6	4	1	Top	74	22	x	x	5
		2	Top	75	23	x	x	10
6	1	1	Flank	92	28	x	x	3
	2	1	Flank	94	28	x	x	3
		2	Flank	90	27	x	x	7
	3	1	Upper Flank	88	27	x	x	10
7	1	1	Top	78	24	x	x	12
		2	Top	78	24	x	x	14
8	1	1	Top	74	22	x	x	12
		2	Top	74	22	x	x	8

Transect Waypoint Excursion Number of 5-min intervals	8 1 1&2 (8)	1 3 1 (4)	1 4 1 (1)	7 1 1&2 (9)	4 2 1&2 (7)	4&6 4 1&2 (8)	2 1 3 (2)	2 3 1 (2)	1 2 2 (3)	2 1 1&2 (4)	1 1 1 (1)	6 2 1&2 (3)	6 1 1 (2)	1 2 1 (2)	1 5 1 (3)	2 2 2 (1)	2 4 1 (1)	4 1 1 (2)	4 3 1 (3)	2 5 1-3 (9)	2 5 dif (1)	6 3 1 (4)
Location on drumlin Depth (feet) (meters) Substrate Sediment cover	Top 74 22 cp+ob m-h	Top 72 22 b+c c	Top 70 21 cgp+b l	Top 78 24 b+oc vl	UF 85 26 c+b l-m	Top 74 22 b c-l	Top 85 26 b+oc l-m	UF 95 29 mix h(mat)	UF 95 29 cp+b m	UF 87 26 mix l-h	Flank 84 25 cp+ob l	Flank 93 28 cp+ob l-m	Flank 92 28 cp+ob l-m	Flank 81 25 cp+ob l	Flank 83 25 b+c c-m	Flank 90 27 c+ob h	LF 105 32 c+ob vh	LF 105 32 c+b m-h	Flank 103 31 cp+ob l-h	LF 112 34 c-bury l-h	112 34 vl	UF 88 27 gc+ob c-vl
Lithothamnion spp.	◪	◪■	◪	◪■	□◪	◪	•◪	•	•□	•	•	•		•	•	•	◪	•□	•			
Strongylocentrotus droebachiensis	◇□	□◪	◪	□◪	•◪	•◪	◇	•	□	◇□	□	◇□	□	◇	□	◇	◇	•	□	•		
Modiolus modiolus	•	◇■	■	◇◪	•◇	•				•			•		•		•			•		
Notoacmaea testudinalis		•	□																			
Asparagopsis hamifera?		•	•	•□	•◪	□◪	◪	◪	□◪	•◪	•□	•	•			•	•					
Agarum cribrosum				•□	◇	◪■	◇□	•					•									
Rhodymenia palmata					•□	□■	•	•			•						◇					
Corallina officinalis						•□																
Obelia geniculata				•		•□										◇						
small white starfish	•□	□◪	□	◪	◇□	□■	□	□	□◪	◇□	□	□	□	◇□	□	□	□	◇□	□	◇□	◇	•
Tautogolabrus adspersus	•	◇□	◇	□■	◇◪	◇◪	◪	◪	□	•◇	□	□	◇□	•◇	◇	◇	◇	◇	◇	•		•
white encrusting organism	◇□	•◇		•◇	◇□	◇	◇	□	◇	•◇	◪	◪■	□	◇□	◇	◪	◪	□	•	•□		
encrusting orange tan sponge	◇	•		•◇		◇			□		□	□◪	□	□	□◪					•□		
Suberites spp.	•			•◇	◇□	•	◇	◇□	•◇	•□	□	□■	□	◇	•	□	□	•□	•	◇		
Halocynthia pyriformis		•	•	◇□	◇	◇□	◇	◇	◇	•◇	□	□	□	□	◇	◇	□	◇	◇□			•
encrusting orange sponge				•◇	•	•◇				•		◇□	□			◇	◇		◇	◇		•
Metridium senile	•			•	•□	•	◇	•◇	◇	•	◇	□		•		•		•◇			□	
Gersemia rubiformis	•	•	◇	•	•	•	◇	•◇	•◇	◇	•	□	•	•	•	◇	◇					
Henricia sanguinolenta	•◇			•◇	◇	◇	•◇		•	◇	◇	◇	◇		•		◇	•	◇	•		
Aplysilla sulfurea	•			•	◇•							◇	◇			•			•			
Asterias vulgaris	◇□	•◇	◇	•◇	•	•	◇		◇	•□	◇		•	◇	◇		◇		◇□	□		•
white divided organism				•◇	•◇													•□				
encrusting tan sponge	•				◇	•◇		◇□				•	•			◇	□	◇				•
Urticina felina	•		•	•	•			•	•	•			◇	•	◇							
Balanus sp.		•◇	•	•	•	•					•		◇	•◇	◇				•	◇		
Myoxocephalus spp.	•	•	•		•		•			•	•			•◇	•	•	◇			•		•
Pleuronectes americanus	•					•				•								•	•	•		
Cerianthus borealis						•														•◇		
hydroids	•	•□	•□	•□	•◪	◪	•	•□	□	•	•□	•◪	•◪	•	□	•	□	•	•	•	◪	
barnacle/spirorbid complex	•□	•		•	•□	•				•◪	□	◇		•□	□		◪	•	•□	•		□

• =rare ◇=few □=common ◪=abundant ■=very abundant; b=boulder c=cobble g=gravel p=pavement o=occassional; c=clean vl=very light l=light m=moderate h=heavy

Trans	WP	Exc	Depth		
			(ft)	(m)	
1	3	1	70	21	T
1	4	1	72	22	T
8	1	1	74	22	T
8	1	2	74	22	T
7	1	1	78	24	T
7	1	2	78	24	T
4&6	4	1	74	22	T
4&6	4	2	75	23	T
4	2	2	85	26	T
4	2	1	86	26	T
2	3	1	95	29	UF
2	1	3	85	26	T
2	2	1	90	27	UF
6	2	2	90	27	F
6	2	1	94	28	F
4	1	1	105	32	LF
1	2	1	81	25	UF
1	5	1	83	25	F
2	1	2	87	26	UF
4	3	1	103	31	LF
1	1	1	84	25	F
6	1	1	92	28	F
2	2	2	90	27	F
2	5	1	112	34	LF
2	5	2	112	34	LF
6	3	1	88	27	UF

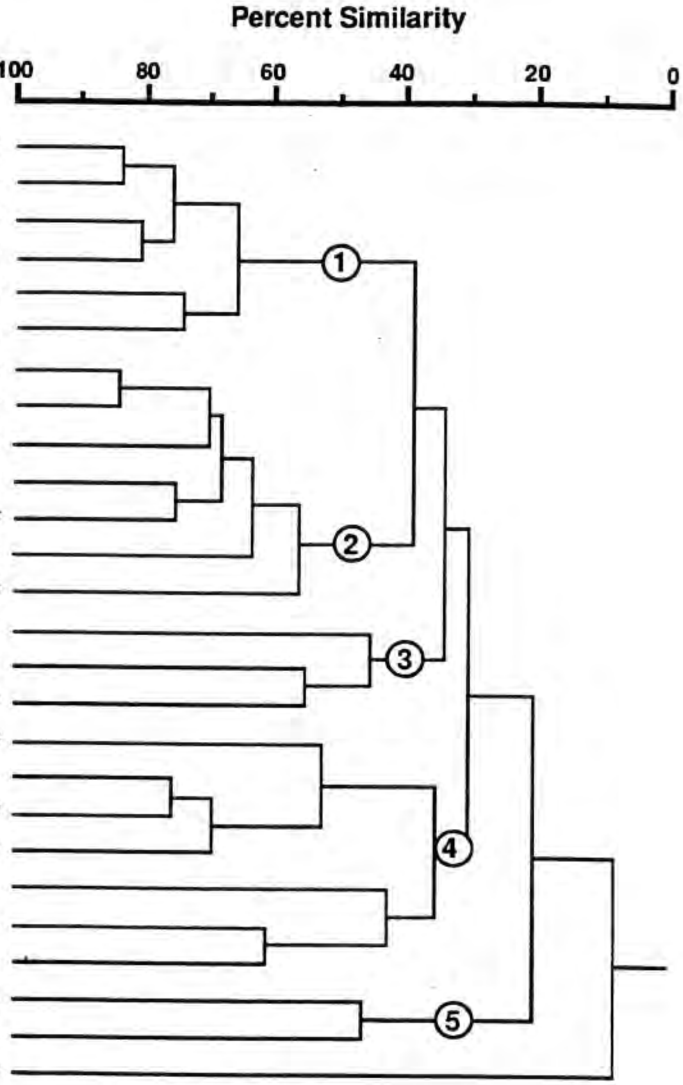


Table 2. Average abundances of taxa in the clusters defined by classification analysis. Abundances are means and standard deviations of the number of individuals per picture (underlines highlight the most abundant taxon in each cluster).

Cluster	**1**	**2**	**3**	**4**	**5**	**outlier**
Location on drumlin	Top	Top	Flank	Flank	Flank	Top
Substrate	b+c	b+oc	cpav+ob	cpav+ob	bury pav	pav+ob
Sediment drape	light-moderate	light-heavy	light-heavy	light-heavy	very heavy	light
Lithothamnion sp.	15.4±3.76	5.6±2.52	2.6±0.97	1.0±0.35	-	-
Asparagopsis hamifera?	1.4±2.83	9.6±3.98	0.4±0.36	-	-	-
Rhodymenia palmata	0.2±0.58	2.7±1.93	0.3±0.36	-	-	-
Agarum cribrosm	0.1±0.14	0.5±0.64	-	-	-	-
Corallina officinalis	-	0.6±0.16	-	-	-	-
Modiolus modiolus	2.1±0.93	1.8±1.49	0.6±0.43	1.2±1.90	0.0-0.2	-
Strongylocentrotus droebachiensis	1.4±0.88	1.4±1.41	0.7±0.62	0.8±0.81	-	-
Notoacmaea testudinalis	0.1±0.09	-	-	-	-	-
Dark red/brown encrusting sponge	0.2±0.22	-	-	-	-	-
Pink fuzzy sponge	0.1±0.24	-	-	-	-	-
Small white starfish	1.9±1.64	3.8±1.49	1.3±0.29	2.8±1.58	0.2-0.4	-
Aplysilla sulfurea	0.2±0.39	1.3±0.76	0.5±0.91	0.3±0.40	-	-
Tautogolabrus adspersus	0.3±0.25	0.5±0.71	0.4±0.34	0.1±0.09	-	0.1
Obelia geniculata	0.1±0.16	0.1±0.19	-	-	-	-
Myxicola infundibulum	-	0.9±1.24	0.1±0.17	-	0.3-0.4	-
Metridium senile	-	0.2±0.05	0.1±0.23	-	-	-
Orange/tan encrusting sponge	0.4±0.56	1.3±0.32	2.7±1.89	0.8±0.83	0.0-0.3	-
White encrusting organism	0.1±0.23	0.5±0.60	1.5±0.50	0.9±1.25	0.0-0.2	0.1
Dendroda carnea	0.1±0.17	0.2±0.05	1.0±0.85	-	-	-
Henricia sanguinolenta	0.3±0.11	0.8±0.93	0.7±0.54	0.3±0.39	-	-
Suberites spp.	-	0.3±0.29	0.6±0.60	-	-	-
Crepidula plana	-	-	4.2±3.54	-	-	-
Terebratulina septentrionalis	-	-	0.1±0.12	-	-	-
White globular tunicate	-	-	0.5±0.91	-	-	-
Red encrusting organism	-	-	0.6±1.04	-	-	-
White divided organism	-	-	0.7±1.27	-	-	-
Homarus americanus	-	-	0.1±0.12	-	-	-
Ophiopholis aculeata	-	-	0.3±0.29	0.1±0.25	-	-
Orange encrusting sponge	0.1±0.10	-	0.9±0.70	-	0.0-0.1	-
Gersemia rubiformis	-	0.2±0.26	0.4±0.66	0.1±0.13	-	0.1
White translucent encrusting organism	0.2±0.23	0.2±0.36	0.3±0.35	-	-	-
Tonicella marmorea	0.1±0.07	-	0.2±0.10	-	-	-
Aplidium spp.	0.5±0.58	0.5±0.29	0.8±0.57	0.7±0.80	-	-
Didemnum albidum	0.3±0.30	0.3±0.25	0.8±0.39	0.7±0.76	0.0-0.1	-
Balanus spp.	0.2±0.24	0.4±0.48	0.3±0.35	0.5±0.60	0.0-0.3	-
Gold encrusting sponge	0.1±0.24	0.4±0.53	0.2±0.21	1.0±1.40	-	-
Tan encrusting sponge	0.1±0.11	-	0.2±0.20	0.5±0.77	-	-
Cerianthus borealis	-	-	-	-	0.3-0.3	-
Asterias vulgaris	0.4±0.37	0.1±0.09	0.1±0.23	0.4±0.46	0.1-0.4	0.1
Orange lumpy sponge	0.1±0.20	-	0.1±0.25	-	-	-
Ciona intestinalis	-	0.1±0.18	0.1±0.12	-	-	-
Urticina felina	-	0.1±0.18	-	0.1±0.16	-	-
Myoxocephalus spp.	-	-	-	0.1±0.14	0.0-0.1	-
Total algae	17.1±5.66	18.8±6.85	3.4±0.63	1.0±0.27	-	-
Total fauna	9.7±3.82	16.8±4.20	21.2±0.56	11.5±5.13	1.7-1.8	0.4